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Research and Development Technical Report

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L-BAND FRONT END SAW FILTERS

B. R. POTTER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The theory and design of L-band SAW Filters for the Global-Positioning System (GPS) RF front end is described. Filters on lithium niobate with loss as low as 4.5 dB at 1233 MHz have been constructed and tested. Filters on ST-quartz have also been designed, fabricated and tested. These devices have insertion loss on the order of 14 to 16 dB and frequency sidelobes of -47 dB with only one weighted transducer. Withdrawal weighted group-type transducers were also designed.

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SECTION I

INTRODUCTION

The performance of the Global Positioning System (GPS) receiver may be greatly improved by incorporation of L-Band Surface Acoustic Wave (SAW) filters. The RF front end of the GPS system is shown in Figure 1. Microwave power incident on the GPS antenna is amplified and diplexed. Signals from the satellite transmitter are fed through the two SAW filters where unwanted signals are filtered out. One frequency or the other is selected by a PIN diode switch that has -50 dB isolation. The SAW filter must operate at L-Band frequencies, have low insertion loss, excellent phase linearity, and good out of frequency band rejection. Actual specifications for the filters are given in the next section.

Low frequency, low-loss SAW filters in the 30 to 440 MHz frequency range are highly developed and insertion loss as low as 2 dB with -50 dB sidelobes have been reported.[1] Greater than 45 dB triple transit suppression is easily achievable and these low frequency SAW devices are being produced regularly.

The 440 MHz upper limit to the three-phase undirectional transducer is a result of the limitations of the fabrication process of the undirectional transducer utilizing gold crossovers. (See Reference 1, page 352, paragraph 3). Three masks are required to fabricate the transducer (See Section V B) and there is a critical alignment of the via hole mask to the electrode mask. As the via hole becomes smaller with the increasing passband frequency of the transducer the mask alignment becomes impossible above 440 MHz.

The group type unidirectional transducer[2] also requires three masks in the fabrication process, but because the electrodes are arranged in groups, the via

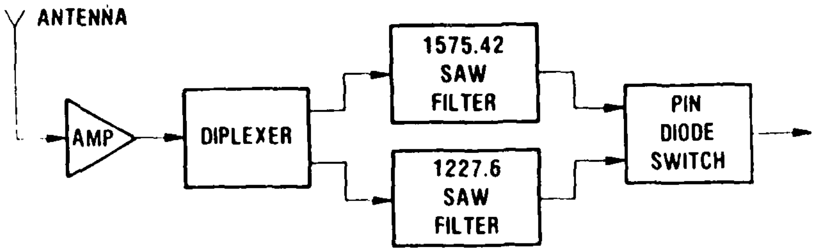


Figure 1. RF Front End of the GPS Receiver.

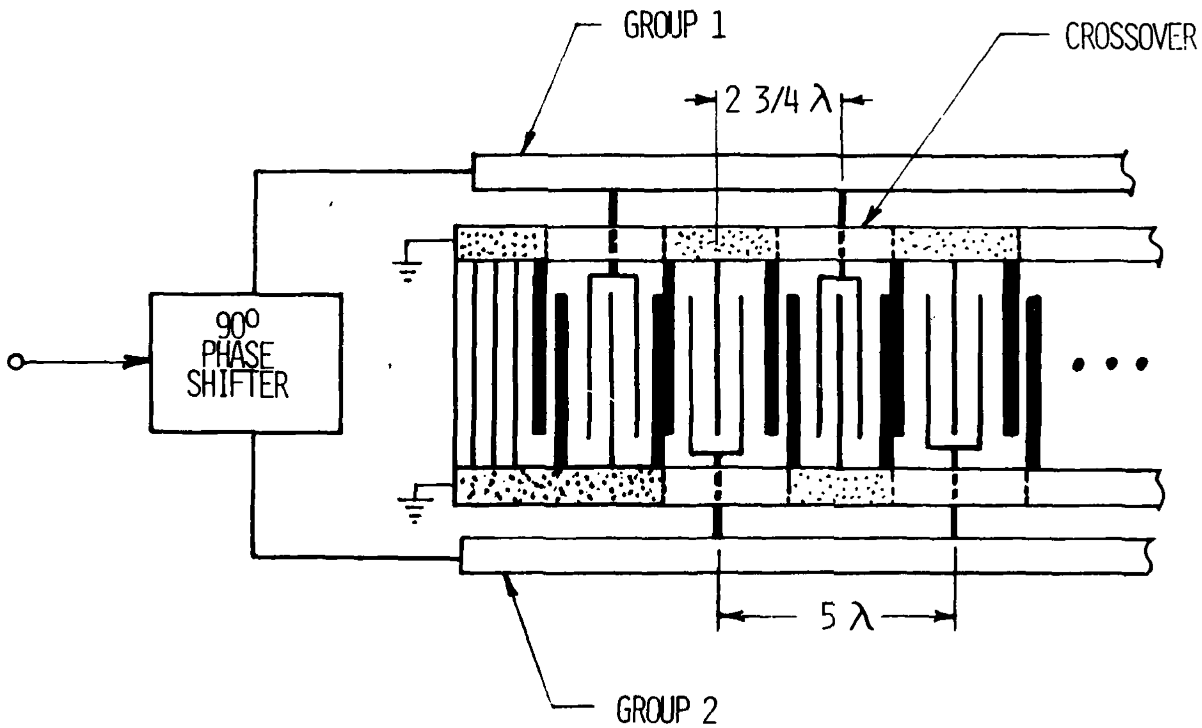


Figure 2. Group-Type Unidirectional Transducer with Crossovers on Both Sides.

holes remain large and the mask alignment for the three levels is relatively straighforward.

Group-type unidirectional transducers were first described by Yamamouchi.[2] These early group structures utilized a meandering group line for single level construction and loss as low as 1.0 dB was achieved at 100 MHz. However, at 1 to 2 GHz on ST-Quartz a meandering ground line would increase the parasitic losses significantly making the gold crossover technique attractive for reducing insertion loss.

SECTION II

PROGRAM OBJECTIVES

The objective of this program was to produce L-Band SAW filters that would meet the requirements of the GPS Manpack program. Specific electrical requirements for the filters are listed in Table I. The center frequencies shown are still firm requirements. However, the 3 dB bandwidth was reduced to 15 MHz. The midband insertion loss requirement has been changed to 12 dB and the frequency sidelobe specification remains at -50 dB. The passband amplitude ripple of less than 1 dB is well within the capability of present low-loss SAW filters. None of the other specifications have changed. Lithium niobate devices were to be studied because of their low insertion loss capability, but because of temperature and phase problems, they are not realistic candidates for the GPS receiver. Group-type unidirectional SAW filters have been chosen as the approach to perform the filter function and meet the system requirements. These type devices will be studied in the main body of this report.

TABLE 1

L-BAND SAW FILTER SPECIFICATIONS

	Lithium Niobate Device	Quartz Device
Center Frequency, GHz	1.2276, 1.57542	1.2276, 1.57542
Bandwidth (3dB)	23MHz	18MHz
Midband Insertion Loss	$<$ 3dB	$<$ 5dB
Rejection (Out-of-Band)	$>$ 50dB	$>$ 50dB
Passband Amplitude Ripple	$<$ 1.0dB	$<$ 1.0dB
Passband Phase Ripple	$< \pm 7.50°$	$< \pm 7.50°$
Shape Factor $\frac{f(50dB)}{f(3dB)}$	$<$ 3:1	$<$ 3:1
VSWR (Input & Output) for 50 Ohm system	$<$ 2.0:1	$<$ 2.0:1
Operating Temperature Range	-54°C to +85°C	-54°C to +85°C

SECTION III

L-BAND GROUP TYPE SAW FILTER THEORY

A. INSERTION LOSS IN L-BAND SAW FILTERS

Insertion loss is of prime importance for any filter that is employed in the front end of a receiver. SAW filters are typical high for insertion loss device and the problem is even more severe at L-Band frequencies where substrate attenuation can be significant. Before the insertion loss contributions can be calculated, the length of each transducer must be known. From Hartmann,[3]

$$\tau = (.73/B) \log R_2, \qquad (1)$$

where τ = transducer length in microseconds,

B = transition bandwidth (-1.5 dB to -2.5 dB), and

R_2 = sidelobe level.

If B is 16.0 MHz and R_2 is -30 dB then the transducer is .07 microseconds long.

1. Propagation Loss

The transducers must be placed at least .05 cm apart to keep RF feed-through down to a reasonable level if the crystals used are .025 cm thick. The propagation path is then .074 cm or .234 microseconds. According to Slobodnik[4],if the material is ST cut quartz,the surface attenuation in a vacuum varies with the square of frequency and is 2.62 dB/microsecond at 1 GHz and 6.6 dB/microseconds at 1.57542 GHz. Propagation loss in a vacuum is then 1.5 dB. If the device is sealed in air an additional .71 dB/microsecond for air loading loss will result.

2. Diffraction Loss

Each transducer will be 111 wavelengths long. As the beamwidth of the transducer is widened diffraction loss goes down and the parasitic finger resistance goes up. To find the point of minimum loss, diffraction loss

has been traded off against parasitic finger resistance loss. The minimum loss point is at about a 50 wavelength beamwidth. Diffraction loss at 50 wavelengths is approximately .75 dB.

3. Parasitic Finger Resistance Loss

To keep mass loading from causing finger distortion, the metal thickness has been assumed to be 500 angstroms. Finger resistance is then .9 ohm per square. For a 50 wavelength wide device the radiation resistance is 1922 ohm and the parallel capactive reactance is 270 ohm. The series resistance of each transducer is then 37 ohm. Parasitic finger resistance is 1.08 ohm per transducer and the insertion loss per transducer is .25 dB for a total of .5 dB for the filter.

4. Package Parasitics and Matching Component Loss

Losses due to package parasitics can be significant especially if the parasitic capacitance is comparable to the finger capacitance. The capacitors used for matching should be high Q chip types and the inductors air wound for high Q. The Q of these components will directly influence insertion loss. The Q that may be achieved at L-Band for air wound inductors is on the order of 10 to 50 depending on the size of the inductor.

5. Total Insertion Loss

The total insertion loss predicted by the preceding calculations is shown in Table 2 as 4.45 dB. This is less than the 5.0 dB in the specification of Table 1. However, it is possible to reduce the loss even further by 1) moving the transducers closer together, and 2) increasing the metal thickness to 1000 angstroms. The first possibility would increase RF feedthrough, however, it is possible that shielding could solve this problem. The second would cause mass loading reflections and loss but it is not known how much distortion would be evident.

TABLE 2

LOSS CONTRIBUTIONS L-BAND FILERS

Propagation Loss	2.2dB
Diffraction Loss	.75dB
Parasitic Finger Resistance	.5dB
Matching Network Loss	1.0dB
TOTAL	4.45dB

B. GROUP TYPE UNIDIRECTIONAL TRANSDUCER THEORY

The configuration is essentially two bi-directional transducers placed 90 degrees out of phase (acoustically) on the substrate. The transducer frequency response will be the same as one of those bi-directional transducers. However, the insertion loss will be low due to the power from the two bi-directional transducers adding in phase in one direction and cancelling in the other.

The transducer design approach is shown in Figure 2. The electrodes are arranged in packets and several packets make up one group. In order to balance parasitics in the transducer each packet is connected to bonding pads after going under an air gap crossover. These crossovers are on both sides of the transducer and balance parasitics between the two groups because they experience the same crossover capacitance and electrode resistance.

The devices are fabricated by visual alignment of three photo-masks. One contact pad per wavelength at L-Band frequencies would make visual alignment of masks impossible. However, four or five wavelengths per contact pad as shown will result in an adequate pad size.

As shown in Figure 2, the fingers of each transducer will be placed in "packets" of 2 to 5 wavelengths each with every other packet 90 degrees or 1/4 wavelength out of phase acoustically with its neighbor. With a +90° electrical phase shift of Group 1 from Group 2, then a wave travelling in the direction of propagation will add in phase with its neighbor. A wave going the opposite direction will then be 180 degrees out of phase with its neghbors and cancellation will occur.

1. Unweighted Transducer Theory

The Fourier series for the group type unidirectional transducer is given in reference 2. When matched, the group-type unidirectional will have a large forward wave and a small backward wave. The expression for the frequency

response of an unweighted filter is given by:

$$F(\omega) = \sum_{n=-3}^{3} \left(S_a(\pi\tau(f-f_o))\right) \cdot \left(S_a \frac{(\omega - 2\pi f_o) - nW}{2} \tau_o\right) \cdot \left(\frac{1}{2}\sqrt{2 + 2\sin\left(\frac{5}{2}\pi + \Phi\right)}\right)$$

where Φ for the backward wave is 180 degrees out of phase from the forward wave.

$S_a x$ = sinx/x

ω = $2\pi f$ where f is frequency, MHz

τ = wavelengths in 1/2 of a group, microsecond

T = wavelengths in one group

f = frequency, MHz; f_o = device center frequency

W = $2\pi/T$, rad/sec

τ_o = overall transducer length, microsecond

Figure 3 shows the square wave modulation of one group of the group-type unidirectional transducer. The overall length of the transducer, τ_o, influences the main response. The period of the transducer, T, determines how close to the main lobe the spurious lobes will be. The time length, τ, of each group of fingers affects the roll-off of the spurious lobes with respect to the main lobe.

The sidelobe locations are given by:

$$f_1 = \frac{f_o}{(1 + 1/N)} \qquad (2)$$

where

f_o = center frequency main lobe, MHz,
f_1 = spurious lobe frequency, MHz,
N = number of electrodes in a group.

f_1/f_o will be .8 for 4 electrodes per group. Since the spurious lobes will be equally spaced in frequency on either side of the main lobe, there will also be a spurious lobe on the high frequency side at $f_1/f_o = 1.2$

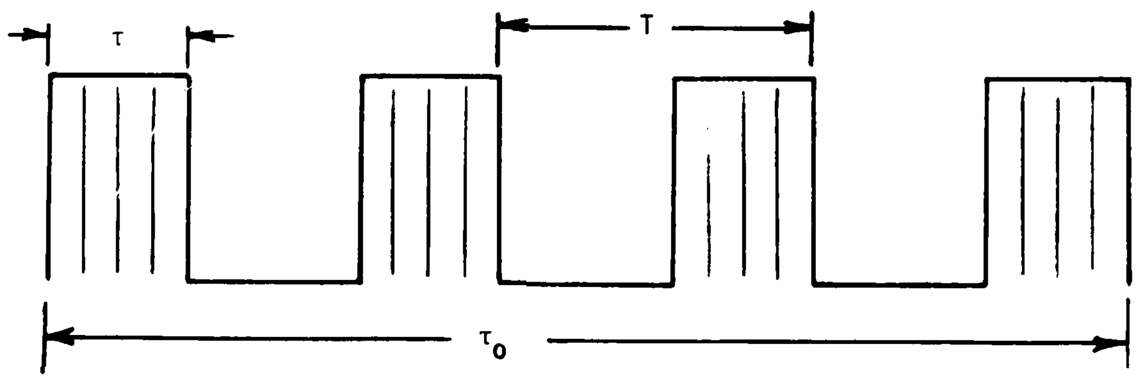


Figure 3. Square Wave Modulation of a Bi-Directional Transducer.

a. Theoretical Results

The above expressions have been programmed into our HP 9825 computing system and some theoretical results have been obtained. Figure 4 is a theoretical frequency response of a 250 MHz prototype device. The program thus far only uses the above equations and no equivalent circuit model has been used to show rejection of the spurious sidelobes. The response of Figure 4 is for both transducers. Note that the first spurious sidelobes are at 200 and 300 MHz. By equation 2 this would correspond to 4 electrodes per group or two active and 2 grounded electrodes per group.

Another way to find the frequency response of a transducer is to perform a Fast-Fourier-Transforme (FFT) on the time envelope. Figure 5 is a plot of the FFT result on the 250MHz group-type transducer with N=4. It must be emphasized that this FFT is for only one transducer whereas Figure 4 was for two transducers.

Note that from Figures 4 and 5 the spurious lobes are down only 4 or 5 dB from the main lobe. For group-type unidirectional filters constructed on lithium niobate this could be a problem. Since the impedance of the lithium niobate transducer is quite low (could be near 50 ohms), the spurious lobes will have relatively low loss unmatched. When the device is matched, only the matching network components will attenuate these lobes. The problem will not be as serious on ST-quartz because the transducer has a relatively high impedance unmatched. When the main lobe is matched, the spurious sidelobes should stay supressed and also be attenuated by the matching network components.

2. Weighted Transducer Theory

The weighting on a group type unidirectional transducer is accomplished basically by weighting one group with apodization or withdrawal of electrodes and then applying the same weighting of the other group. Taking a FFT of one of the groups will then give the unmatched frequency response of the transducers.

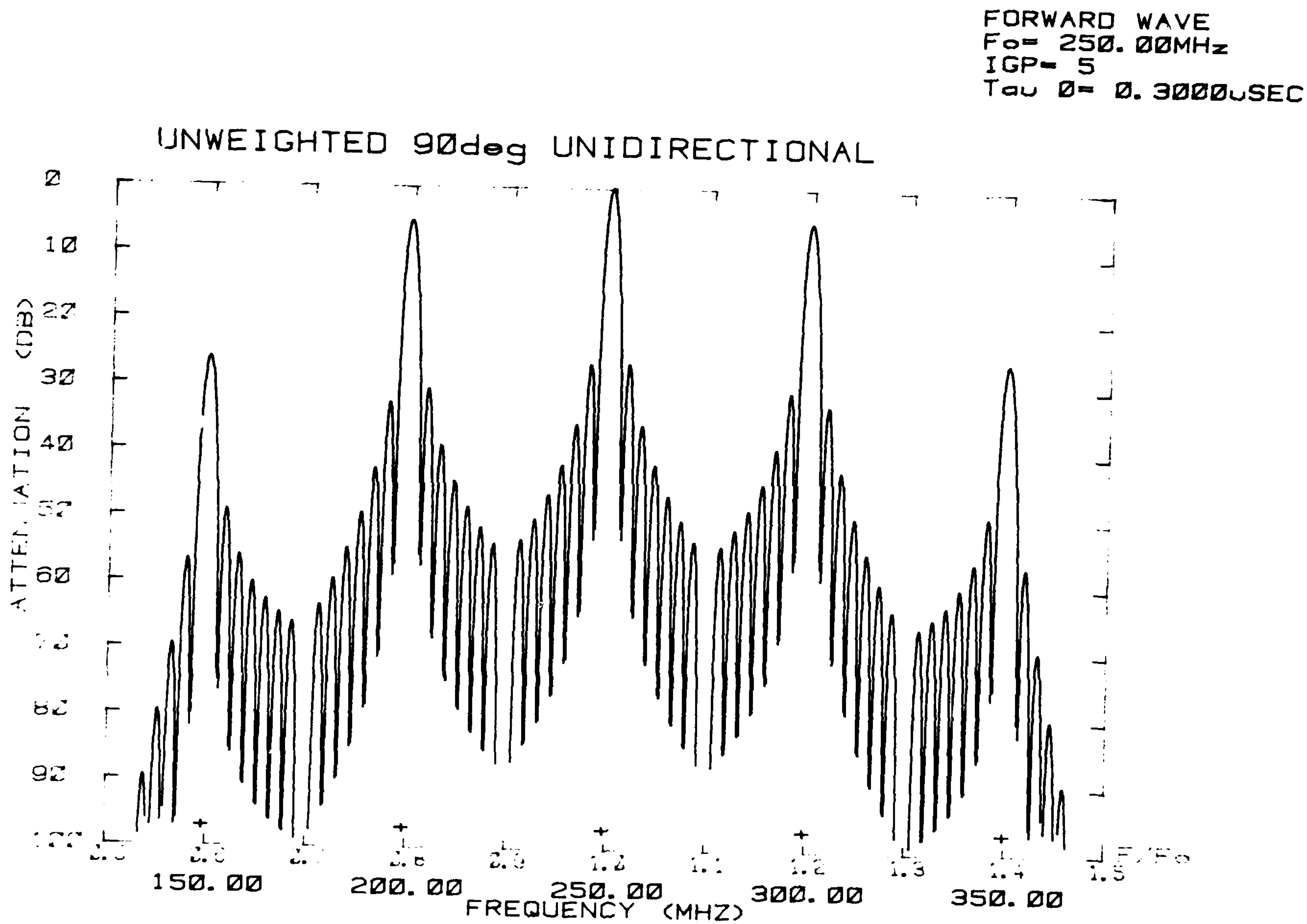


Figure 4. Theoretical Frequency Response of an Unweighted Group-Type SAW Filter at 250 MHz.

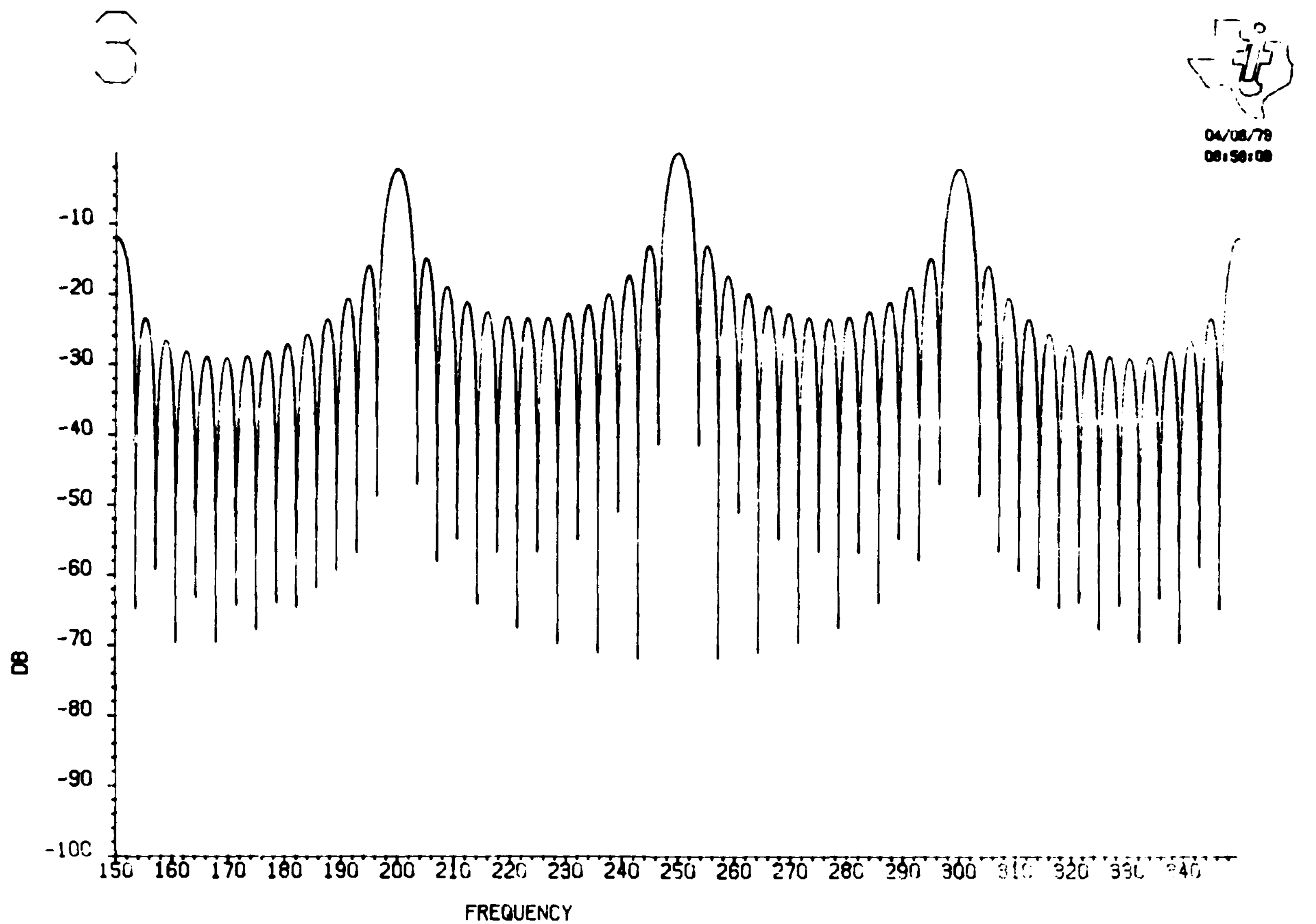


Figure 5. FFT of one Group Similar to Figure 3.

Both types of weighting will be examined in this report.

a. Apodized Weighting and the Group Type Structure

The most difficult problem with over-lap weighting is developing a scheme that will allow the parasitics to be balanced and the surface wave velocity under the electrodes to remain constant. Figure 6 is the representation of how this has been accomplished. In Figure 6 (A) various packets of one group of a transducer are shown with typical weighting on them. Packet A has very little weighting and is the same as E if the weighting scheme is symmetrical. Packets B and D also have the same weighting, and the full overlap of the transducer occurs at the center. In order to balance parasitic capacitance, resistance and inductance for both groups, a scheme must be worked out to have crossover ground bars on both sides of the transducer. The technique is depicted in Figure 6 (B), where at the center of the transducer the group is flipped as shown. In Figure 6 (C), Group 2 is now added shown in the dotted lines. Packets A and A', though on different ends of the transducer, interact with each other because they are a net 90° out of phase on the substrate. C interacts at the center of the transducer with C' and D interacts with D'. The arrows at A and E' indicates the direction in which the connections are made to those packets. Figure 2 showed how the connections were made on both sides of the transducer for an unweighted transducer. The weighted transducer will look the same except for the apodization and flipping at the center.

A plot is given for the theoretical frequency response of the apodized transducer in Figure 7. The weighting is Dolph-Chebyhev with a Taylor series approximation. The assumed sidelobes are -35dB and there are 5 wavelengths between packets. This puts the spurious lobes at $.8f_o$ and $1.2f_o$. Further

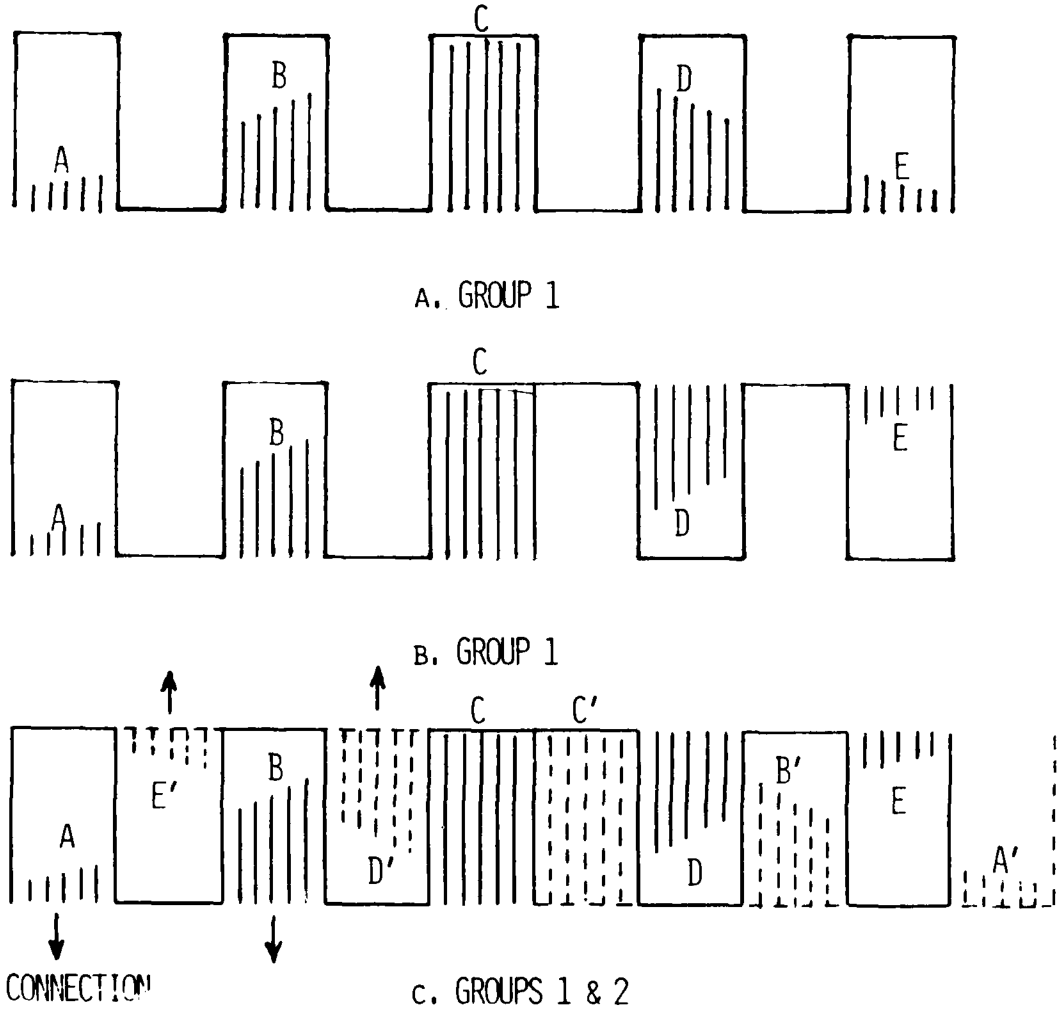


Figure 6. Apodizing the Group-Type Unidirectional Transducer.

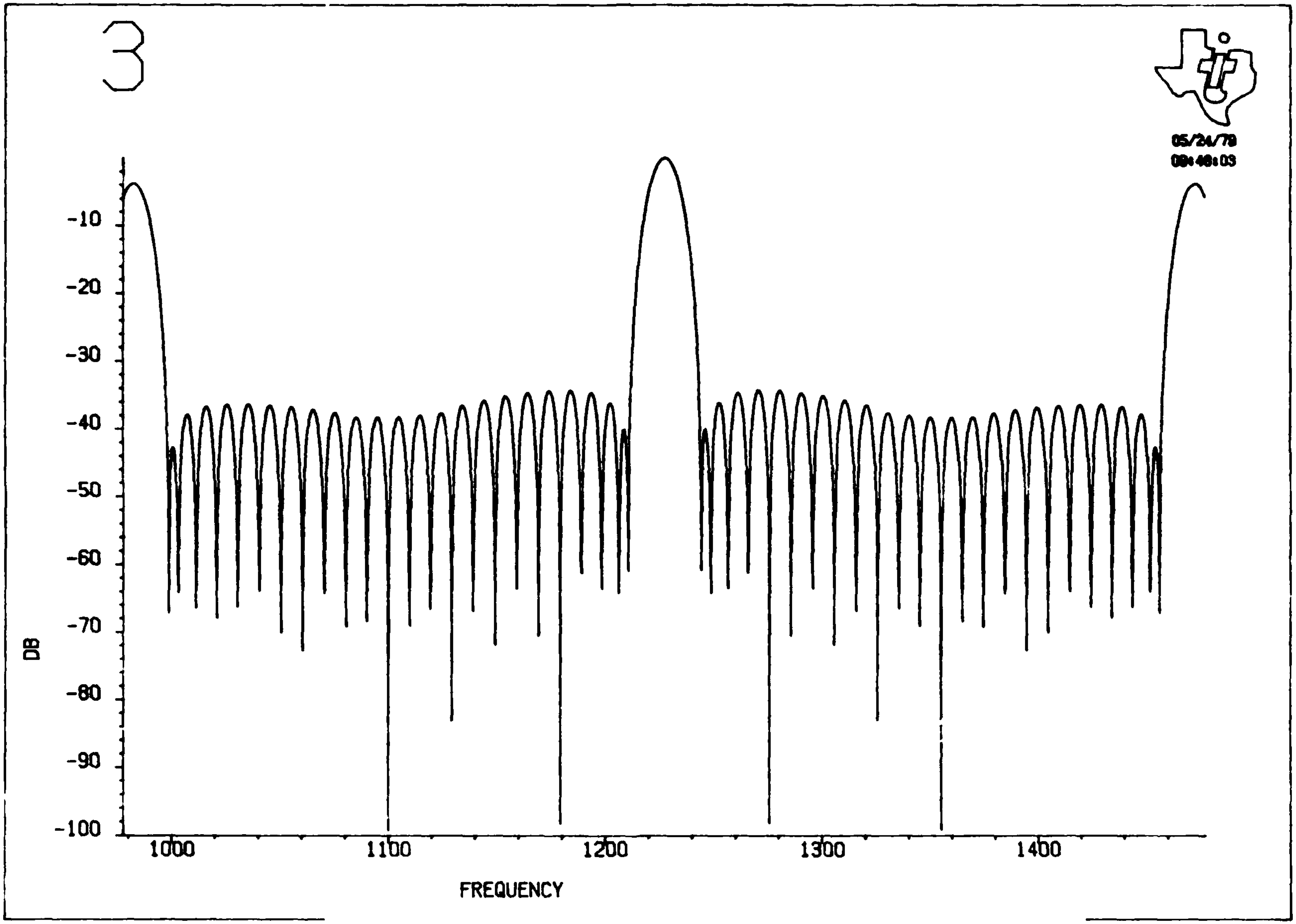


Figure 7. FFT of one Group of the Apodized Transducer.

details of the actual waveform are given in the appendix.

b. Withdrawal Weighting with the Group Type Unidirectional Transducer

Withdrawal weighting is performed simply on the group type unidirectional transducer by applying the weighting to one group and then the same weighting to the other group. The withdrawal is performed by the use of a computer program developed at Texas Instruments in the early 1970's. The methods of withdrawal is described in a paper by Hartmann.[5] A typical frequency response of one transducer is shown in Figure 8.

C. HARMONIC DEVICES

Low loss harmonic filters are theoretically possible using the group type unidirectional structure. The spurious lobes will be closer in to the main lobe because at the fundamental the spurious lobes are closer to the fundamental at the lower frequency, and the spacing will stay the same at the harmonic. This may not be a totally limiting factor in that the location of the spurious lobes may be controlled to some extent by going to the minimum number of wavelengths in a packet of fingers. (See Equation 2).

In designing a harmonic device it is necessary that the amount of phase shift between groups at the fundamental be such that at the harmonic frequency there is a net 90° of shift. One other limiting factor is the number of wavelengths of transducer at the fundamental may cause too few of samples to do an adequate job of withdrawal weighting a transducer.

This is the case with the GPS filters where at the third harmonic the device has 80 wavelengths per transducer. Then at the fundamental there is only 80 divided by 3 or 27 wavelengths to weight the transducer. An example of the fundamental of the 1575.42 MHz device is shown in Figure 9. Note that the spurious lobes are only (.8)(525.14) = 420 and 525-420 = 105 MHz from the fundamental. No harmonic L-Band filters were produced under this program.

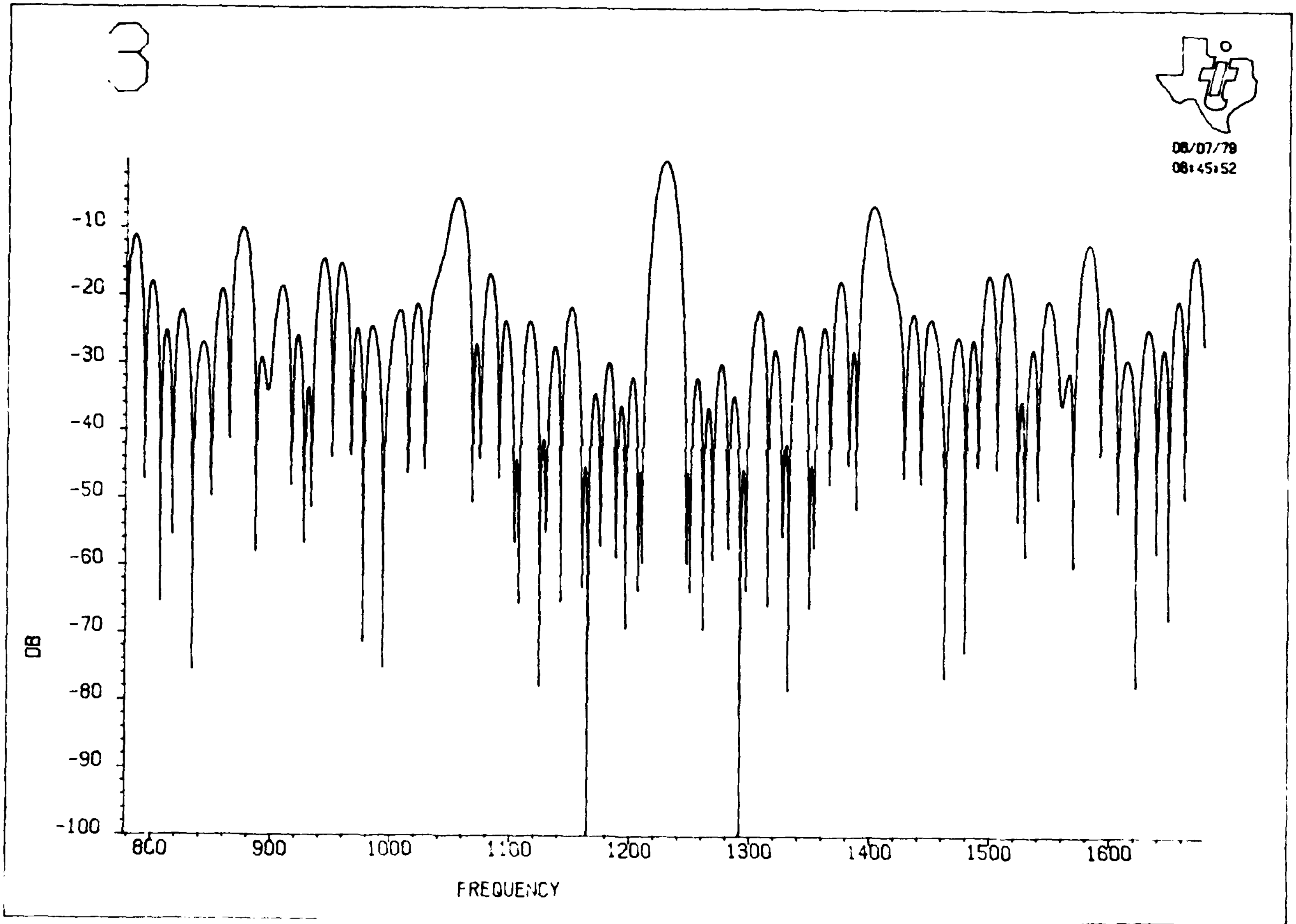


Figure 8. FFT of a Withdrawal Weighted Transducer.

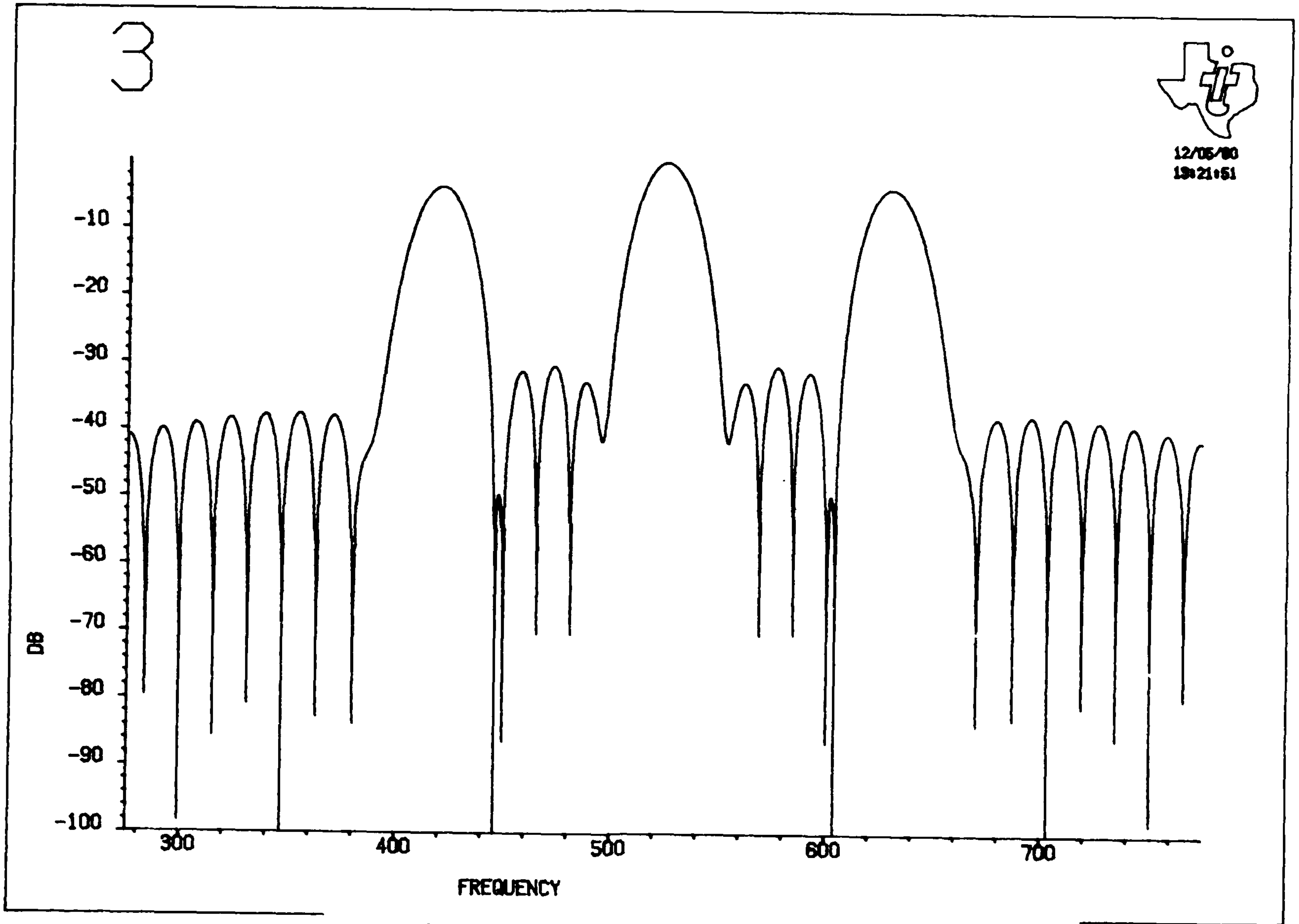


Figure 9. Frequency Response of the Fundamental of a Harmonic Group-Type Filter.

SECTION IV

IMPEDANCE MATCHING AND PHASING OF THE GROUP TRANSDUCER

The first group-type unidirectional transducers used 90° lengths of coaxial line to produce the necesary phase shift.[2] This worked well for lithium niobate devices where the transducer impedance was near 50 ohms. However, for devices constructed on ST-quartz matching in and out of the coaxial line would present a difficult problem. Malocha[6] developed a technique for matching and phasing the group-type unidirectional transducer on ST-quartz using only two components.

Consider the schematic for the group-type transducer shown in Figure 10. Z'_{12} is the input impedance of the device phased with components X_1 and X_2. The phase shift from phase 1 to phase 2 through X_1 and X_2 will most likely be achieved with inductors for ST-quartz and at least one will be a capacitor for lithium niobate substrates. These component values can be calculated from the following:

$$X_1 = A(\cos\theta + \sin\theta), \tag{3}$$

$$X_2 = A(\sin\theta - \cos\theta), \tag{4}$$

$$Z'_{12} = |A\cos\theta|. \tag{5}$$

A and can be calculated from the transducer parameters.

$$A = \left[n f_o C_s \sqrt{(2\pi)^2 + (8k^2 n)^2} \right]^{-1} \tag{6}$$

and

$$\theta = \tan^{-1} \left[\frac{\pi}{4k^2 n} \right] \tag{7}$$

where

f_o = center frequency, MHz

n = number of electrodes in 1/2 transducer

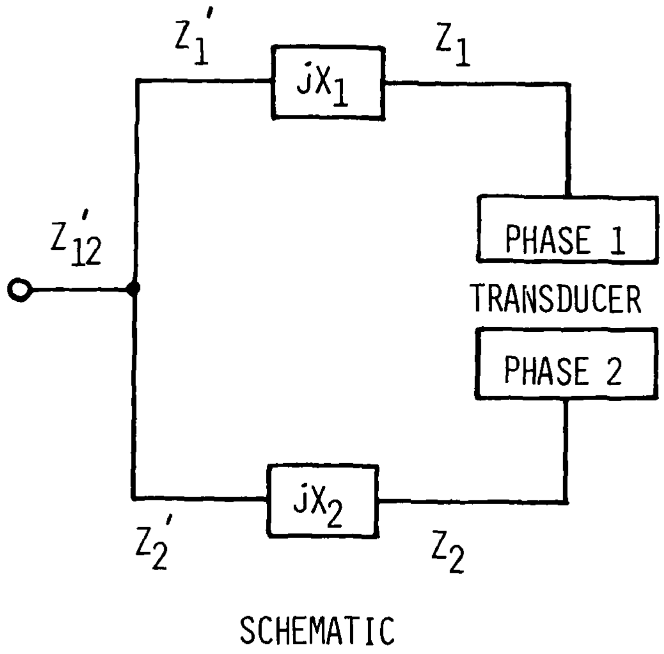


Figure 10. Series Tuning Network for the Group-Type SAW Transducer.

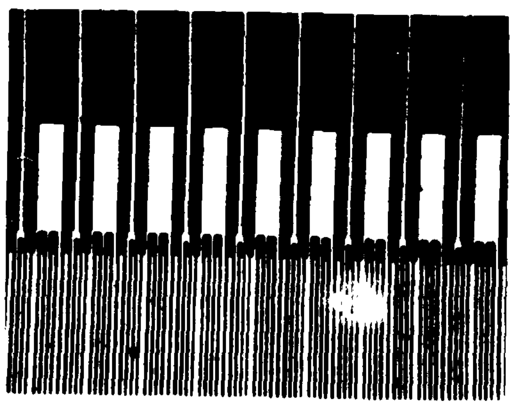


Figure 11. Transducer Structure for a 1227.6 MHz Unweighted SAW Filter.

C_s = capacitance one finger pair

k^2 = coupling coefficient

It is interesting to note that θ only depends on the coupling coefficient and the number of finger pair. However, any significant parasitic capacitance or inductance can change θ .

Equations 3-7 will be used in making component calculations in the next Section.

SECTION V

DEVICE FABRICATION AND PACKAGING

A. PHOTOMASK CONSTRUCTION

The photomasks are fabricated using either one of two electron-beam patterning machines in Texas Instruments Central Research Laboratory. The masks are 5.08 x 5.08 x .15 cm glass plates with 200 angstroms of chromium deposited by evaporation. A negative E-Beam resist is spread in a thin coating over the chromium. The pattern is exposed with an electron beam and lines as small as .4 micron have been fabricated. The resist is developed and the unwanted chrome is removed using an ion-milling process.

The first level mask contains the interdigital finger structure and is shown in Figure 11. This is an unweighted transducer with 5 acoustic wavelengths in the periodic structure of a group. Figure 11 shows the transducer structure for the unweighted 1227.6 MHz ST-quartz device. Only one side of the transducer is shown but both sides are constructed the same. The parasitics are balanced with the pads shown as ground on both sides and the two phases going between the ground pads on both sides of the transducer.

B. DEVICE FABRICATION

Fabrication of the group-type unidirectional transducer utilizing air insulated crossovers was described by Rosenfeld.[4] The steps in the fabrication process include 1) defining the aluminum finger pattern on the substrate, 2) sputtering a layer of moly and etching the via holes, 3) sputtering titanium tungsten-gold, 4) elecrochemically plating thick gold reflections from the large

ground bar. The device still has crossovers, and 6) etching away the moly to leave the air insulated gold crossovers. Figure 12 shows an SEM of the air insulated crossovers.

This proven fabrication process was developed at Texas Instruments and is highly developed. Therefore, no funds from this contract were expended in developing the process further.

C. E-BEAM MASK MAKING DIFFICULTIES

The fabrication of upper L-Band *SAW devices dictates that E-Beam mask making facilities be employed. For example, a SAW filter at a frequency of 1575 MHz requires interdigital lines and spaces of only 0.48 microns. This is near the limit of existing E-Beam machine capabilities and can only be achieved when the facility is fine tuned and working to its' peak potential. Since less than 1 micron resolutions are not generally required for IC fabrication, very little of such experience exists at T.I. As a result, considerable difficulties were encountered in our attempt to produce masks suitable for this program. This in turn limited our ability to experimental evaluate many of the theoretically generated designs. It is uncertain at this time whether the masks necessary to follow through with the experimental portion of this effort will be available by the specified contract delivery dates.

D. PACKAGING

Packaging of the devices in a low parasitic environment is crucial to the performance of the filters. The following concepts have helped in packaging L-Band SAW filters:

1. No RF feedthroughs may be used between the transducers and matching networks.

*L-Band denotes frequencies between 890 MHz and 2000 MHz for purposes of this report.

5Kx

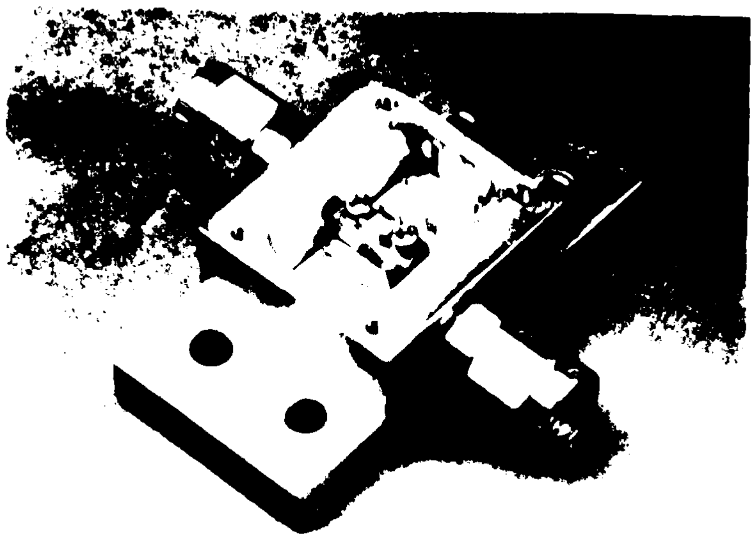
Figure 12. SEM of Air Insulated Gold Crossovers.

PACKAGING (CONTINUED)

2. Low parasitic capacitance must be maintained with PC boards that contain the matching components.

3. RF shielding must be incorporated to eliminate feedthroughs.

Two packages have been employed to accomplish the above goals. They are shown in Figure 13a and 13b. Figure 13a is the prototype package and has been used for testing the devices on this contract. Figure 13b will be the final package for the GPS receiver.



a. Prototype Package.

b. GPS Final Package.

Figure 13. L-Band SAW Filter Packages.

SECTION VI

DEVICE DESIGNS AND RESULTS

Group type unidirectional SAW devices have been designed, constructed and tested at the following frequencies:

1. 961MHz unweighted, crossovers on one side
2. 250MHz unweighted, crossovers on one side
3. 1227.6MHz unweighted, crossovers on both sides (ST-quartz and lithium niobate)
4. 1227.6MHz weighted, crossovers on both sides.

Other devices were designed but masks of sufficient quality for device fabrication were not obtained during the time available for this program.

A. LITHIUM NIOBATE DESIGN AT 961MHz

The first group-type unidirectional filter produced at Texas Instruments was constructed on lithium niobate with a center frequency of at 961 MHz. The two transducers were 95 wavelengths long, constructed like Figure 14 with crossovers only on one side. The transducer beamwidth was .015 inches or 39 wavelengths. From equations 3-7 this means that X_1 = 22 ohms or an inductor of 4nh. X_2 = 10 ohm or a capacitor of 16 pf. The transducer beamwidth was not chosen correctly to utilize the series tuned approach to matching and phasing the transducers.

The approach employed to match the device was to use a 90° long coaxial line with matching components at each end of the line. This was a crude method and may have contributed to the insertion loss. The insertion loss after matching was measured to be 6.5 dB and was probably due to narrow fingers and poor matching.

A photograph of one transducer is shown in Figure 15. Both groups are connected at one side of the transducer utilizing the gold crossover. This resulted

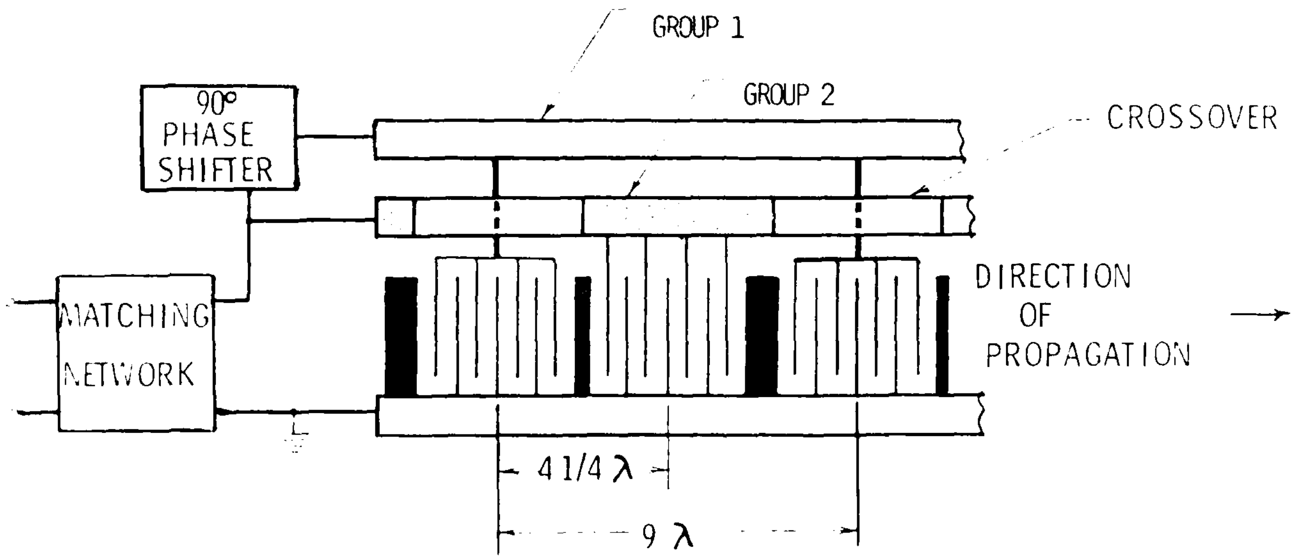


Figure 14. Group-Type Unidirectional Transducer with Crossovers on one Side.

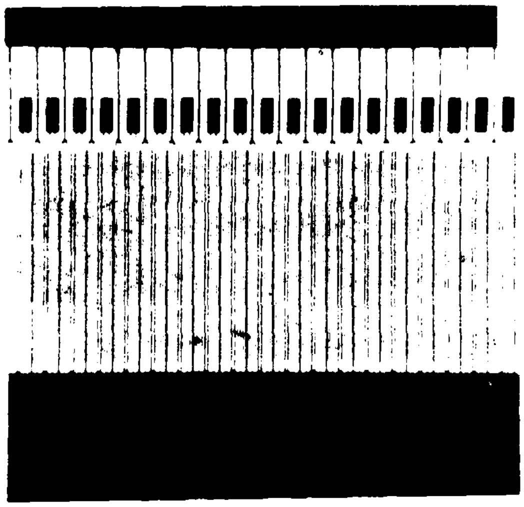


Figure 15. 961 MHz Group-Type Transducer.

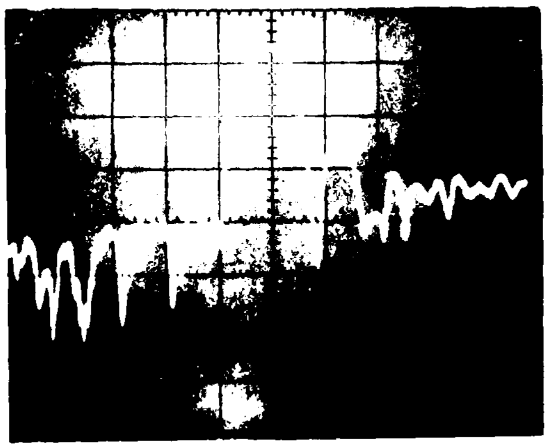


Figure 16. L-Band SAW Filter with 6.5 dB Insertion Loss.

with parasitics that were not balanced and contributed further to additional insertion loss and the inability to totally match the filter.

The main passband response of the device is shown in Figure 16. Since it is an unweighted transducer, the response shows poor sidelobes. RF feedthrough is also an obvious problem with the crosstalk level only 30dB down from the main passband. Additional packaging effort could have reduced the crosstalk. Not shown are the spurious lobes at 768.8 and 1153.2MHz. These lobes occurred exactly where the theory would have predicted them.

B. 250MHz L-BAND PROTOTYPE ON ST-QUARTZ

To try to understand the group-type unidirectional transducer without the packaging parasitics that occur at L-Band frequencies, a device was constructed at 250 MHz on ST-Quartz. The transducer was 65 wavelengths long, which represents a bandwidth of just over 1 percent at 250 MHz. The period, T, of the transducer was 5 wavelengths long so so that the spurious lobes would appear at .8 x 250 = 200 MHz and 1.2 x 250 = 300 MHz.

The series tuning approach was chosen to see if the technique could be used at L-Band frequencies. Employing equation 7, θ turned out to be 86.56 degrees and A from equation 6 was 624. The two phasing inductors came out to be 421 nh and 373 nh. Z'_{12} from equation 5 was predicted to be 37 ohms. Parasitic feed-through capacitance of the package shown in Figure 17 changed considerably the final values of the phasing inductors from 400nh to between 100 and 200nh. More importantly Z'_{12} became very low in impedance and capacitance. Therefore, a matching network was necessary and the total number of components needed per transducer was four.

A photograph of the final transducer structure is shown in Figure 18. There are two large ground bars in the interdigital finger structure. One of them, as shown in Figure 14 , is 1 wavelength wide and the other 1/2 wavelength wide with 1/4

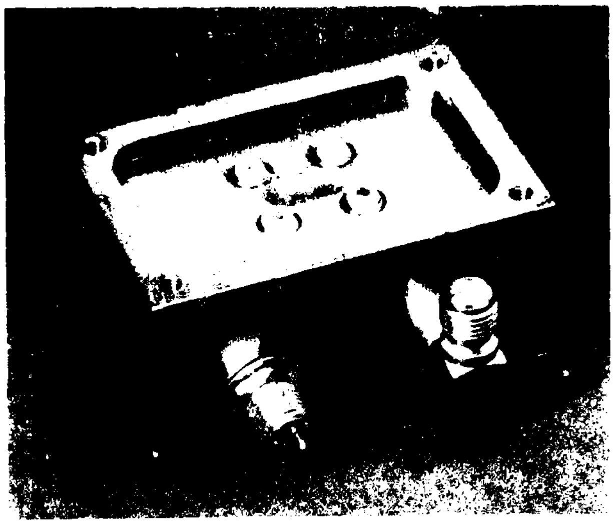


Figure 17. Package for the 250 MHz Filter.

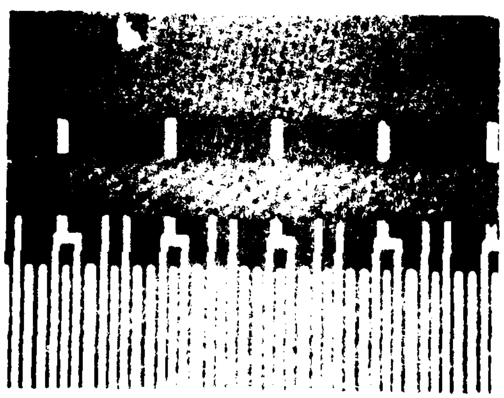


Figure 18. 250 MHz Group-Type Transducer Structure.

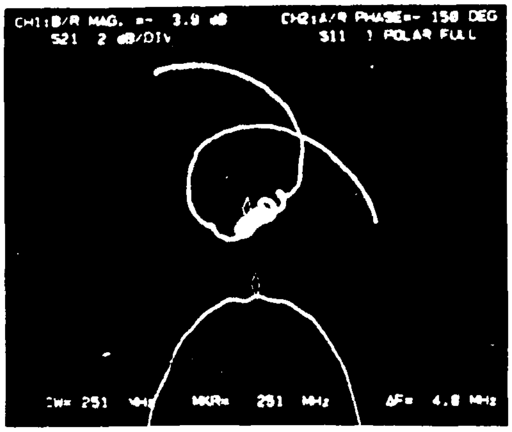
wavelength between the two. It is hoped that this might cut down on spurious reflections from the large ground bar. The device still has a crossover on only one side as did the 961 MHz device.

The electrical results from the device were excellent. The insertion loss in the middle of the passband was 3.9 dB, when matched and phased to 50 ohms. Figure 19a shows the inband response and the Smith chart of the impedance of one transducer. A small amount of ripple is evident in the passband and could be caused by two things. The first is acoustic reflections of the 1/4 wavelength fingers in each group. The second is the possibility that the device was not perfectly phased due to imbalance of parasitics. Figure 19b shows the first spurious sidelobes quite clearly at 200 and 300 MHz. They are suppressed due to the matching and phasing network only acting on the mainlobe.

C. 1233 MHz UNWEIGHTED LITHIUM NIOBATE FILTER

A filter was designed using Y-Z lithium niobate as a substrate and 15 MHz bandwidth as a design goal. Figure 20a is the frequency response of the device showing an insertion loss of 4.6 dB. The filter was unweighted so the sidelobe level was -19 dB near in. Figure 20b shows the first three spurious sidelobes with an apparent null occurring in each spurious passband.

To insure that the spurious sidelobes from each transducer will not reinforce each other, each transducer is designed with spurious lobes at different frequencies. Equation 2 can be used to determine where the lobes will be located with various "packet" sizes for the group structure. For the device of Figure 20 N in Equation 1 was 4 for one transducer and 6 for the other. The resulting first spurious lobe frequencies are 1056 and 986MHz.

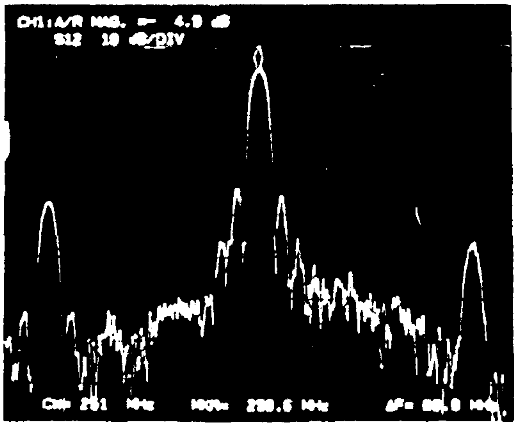


0 dB

2 dB/Div

251 MHz .8 MHz/Div

a. In-band Response and Phase.



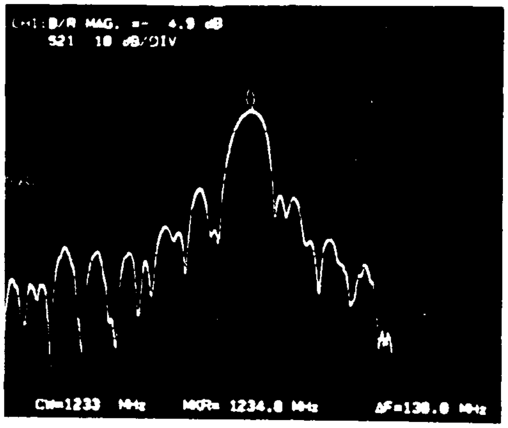
0 dB

10 dB/Div

250 MHz 10 MHz/Div

b. Spurious Sidelobe Response.

Figure 19. 250 MHz Filter Results.

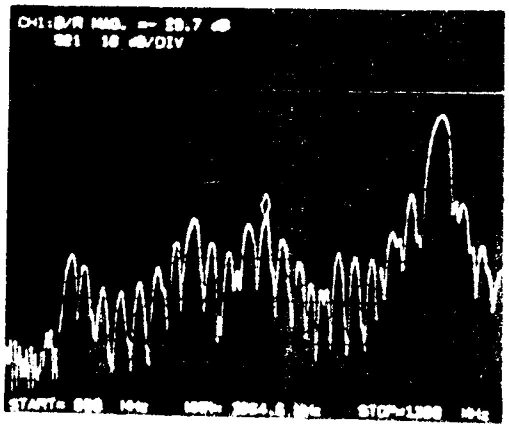


0 dB

10 dB/Div

1234 MHz 20 MHz/Div

a. In-band Response and Near-in Sidelobes.



0 dB

10 dB/Div

1065 MHz 40 MHz/Div

b. Spurious Sidelobe Response.

Figure 20. 1233 MHz Unweighted Lithium Niobate Filter Results.

The matching network for the device of Figure 20 consists of two series matching components per transducer. Connected to phase 1 of the transducer is a 9 nh inductor and to phase 2 a 3.3 pf capacitor. Bond lead parasitic inductance was taken into account to determine these two values. The output is taken at the connection point between the two components where the impedance is real and about 50 ohms. The matching technique is described in more detail in reference 6.

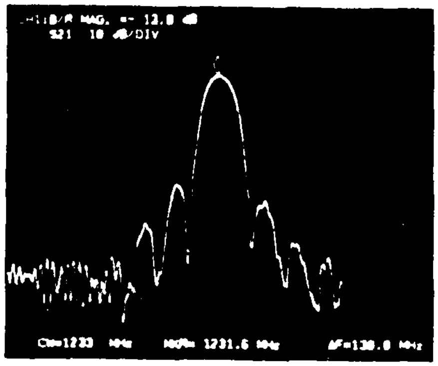
D. <u>1233MHz UNWEIGHTED ST-QUARTZ FILTER</u>

To this date both matching and phasing of an ST-Quartz device have not been accomplished at the same time. It will require 4 components to do this and the present package being utilized will accomodate only two components.

An ST-Quartz device that has been matched but not fully phased is shown in Figure 21. It is an unweighted device designed for 15 MHz bandwidth. The near in sidelobes are down 30 dB but will come up as the device is phased properly. Ripple in the passband also indicates improper phasing.

Figure 22 is the same unweighted device with one transducer reverse phased. Note the good sharp null in the passband indicating proper phasing. Also displayed is the Smith Chart impedance of the device at the input to the phasing network. Whether the device is forward or reverse phased, this will be the impedance of the transducer. A matching network can then be calculated to both match and phase the device to 50 ohms.

Figure 23 shows the main passband of the device along with the spurious response on the low frequency side of the two transducers. These lobes are suppressed 45 dB in this non-phased device and should be down over 50 dB in a properly matched and phased device. In fact, on the 250 MHz unweighted prototype device that was properly matched and phased, the spurious lobes are down -55 dB.

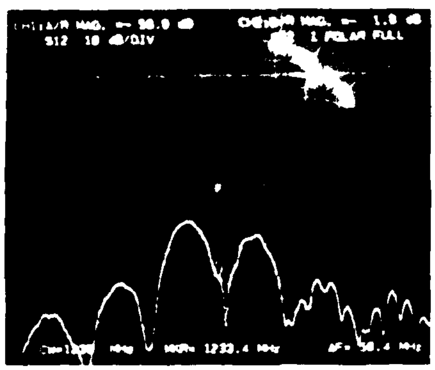


0 dB

10 dB/Div

1232 MHz 20 MHz/Div

Figure 21. Unweighted St-Quartz Filter at 1233 MHz.



0 dB

10 dB/Div

1233 MHz 10 MHz/Div

Figure 22. Frequency Response of the St-Quartz Filter with one Transducer Reverse Phased.

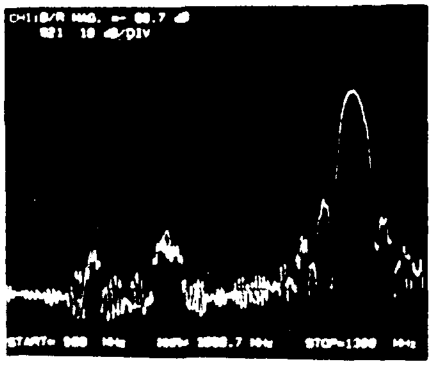


Figure 23. Unweighted St-Quartz Filter Spurious Sidelobe Response.

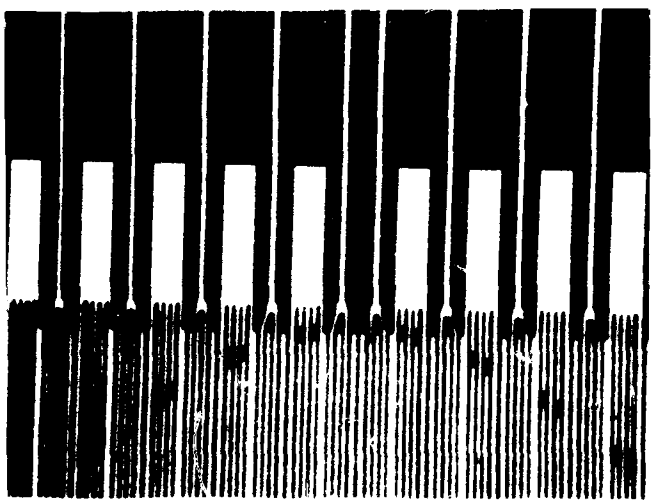


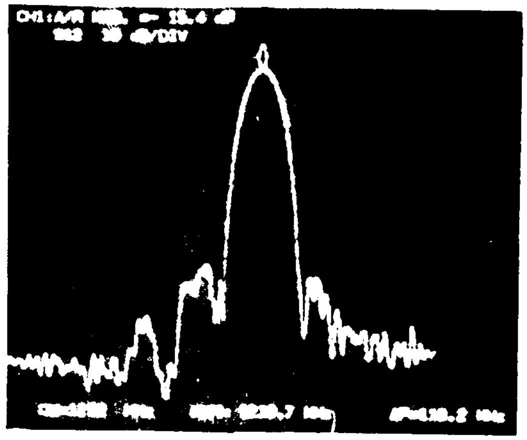
Figure 24. Overlap Weighting Scheme for Group-Type Unidirectional Transducers.

E. 1233 MHz WEIGHTED ST-QUARTZ FILTER

The only scheme to reduce frequency sidelobes implemented to date has been overlap weighting. Figure 24 shows the weighting in the center of the apodized transducer. The pads shown are ground pads and the device has balanced parasitics with crossovers on both sides. This transducer is a Taylor Series approximation to the Dolph-Chebyshev weighting function with -35dB sidelobes.

Figure 25 shows the frequency response with -45dB sidelobes. The unweighted transducer will have -13dB sidelobes, so that the theoretical sidelobe level would be -48dB. This is in agreement with the approximate sidelobes realized.

A null in the mainlobe can be obtained when the weighted transducer is reverse phased. Figure 26 is the frequency response and polar plot with the unweighted transducer matched and the weighted transducer reverse phased. The impedance is such that two additional matching components will be required to match and phase the device.

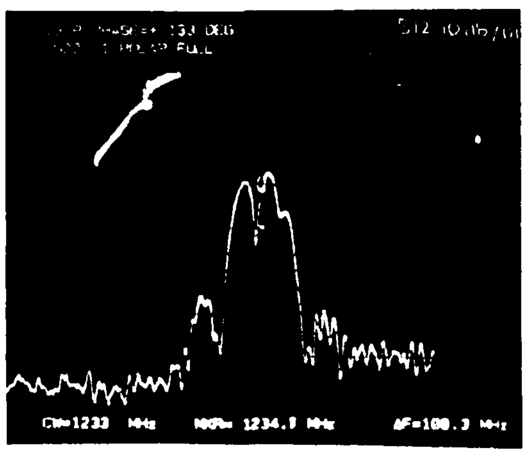


0 dB

10 dB/Div

1234 MHz 18 MHz/Div

Figure 25. Matched(but not phased) Frequency Response of the St-Quartz Weighted Filter.



0 dB

10 dB/Div

1234 MHz 18 MHz/Div

Figure 26. St-Quartz Filter with the Weighted Transducer Reverse Phased.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

The mask making process has been troublesome but good devices have been constructed. Lithium niobate filters wth 4.6 dB of insertion loss have been proven feasible at 1233 MHz. Sidelobe weighting using a special apodization technique has been proven to work well and an ST-quartz device with -47 dB sidelobes was observed. Withdrawal weighting was shown to be theoretically possible but never proven. Package parasitics were difficult to overcome but a new package promises to eliminate parasitic capacitance -- the most difficult packaging problem.

Many parameters were never measured because masks for the high frequency devices were never adequately constructed. One of these parameters is the phase linearity tracking between the two frequencies over temperature. This parameter is crucial to proper operation of the GPS system.

It is recommended that work be continued in the L-Band filter area. An alternate approache to improve performance presently being tried at Texas Instruments are 2nd and 3rd harmonic filters. These approaches have their own special problems with spurious lobes being too close and sidelobe suppression being quite difficult. Also, direct E-Beam slice writing could be employed to eliminate difficult fabrication steps and improve resolution.

SECTION VIII

REFERENCES

1. B.R. Potter and C.S. Hartmann, "Low Loss Surface-Acoustic-Wave Filters", IEEE Trans. on Parts, Hybrids and Packaging, Vol. PHP-13, No. 4, Dec. 1977, pp. 348-353.

2. K. Yamanouchi, F. Nyffeler, and K. Shibayama, "Low Insertion Loss Acoustic Surface Wave Filter using Group Type Unidirectional Interdigital Transducer," 1975 Ultrasonic Symp, Proc., IEEE Cat. No. 75 CH0994-4SU, pp. 371-321.

3. C.S. Hartmann, D.T. Bell, Jr., and R.C. Rosenfeld, "Impulse Model Design of Acoustic Surface Wave Filters," Special Joint Issue of IEEE Trans-Microwave Theory and Techniques, MTT-21, 162 (1973), and IEEE Trans-Sonic and Ultrasonics, SU-20, 80 (1973).

4. A.J. Slobodnik, "A Review of Material Tradeoffs in the Design of Acoustic Surface Wave Devices at VHF and Microwave Frequencies," IEEE Transactions on Sonics and Ultrasonics, SU-20, October 1973.

5. C.S. Hartmann, "Weighting Interdigital Surface-Wave Transducers by Selective Withdrawal of Electrodes," 1973 IEEE Ultrasonics SYMP. Proc., Cat. No. 73 CH0807-8SU, p. 423

6. D.C. Malocha and B.J. Hunsinger, "Tuning of Group Type Unidirectional Transducers," IEEE Trans. Son. and Ultras., Vol. SU-26, May 1979, pp. 243-245.

7. R.C. Rosenfeld, C.S. Hartmann, and R.B. Brown, "Low-Loss Unidirectional Acoustic Surface Wave Filters," Proceedings of 28th Annual Symposium on Frequency Control, U.S. Army Electronics Command, Fort Monmouth, NJ (1974).

APPENDIX

GROUP TYPE TRANSDUCER DESIGN AND COMPUTER PROGRAM

The design of a weighted group type unidirectional transducer will be presented in this section. The following steps are necessary in executing the design:

1. Determine the waveform weighting function.
2. Calculate the exact transducer length for one group.
3. Run the waveform computer program.
4. Use the output of the waveform program to do an FFT to analyse the frequency response of the transducer.
5. Use the output of the waveform program to run the main group-type transducer program to obtain mask making cards.

These steps will be discussed in the following sections and an actual design will be presented. The design is for the apodized transducer of the device in Section IV D.

A. WAVEFORM WEIGHTING FUNCTION

Many different weighting functions are possible, but there is one that seems to combine optimum length of a transducer with sidelobe level. That function is known as the Taylor Series approximation to the Dolph-Chebyshev Polynomial. A copy of that program has been included along with the output from it.

One data card is required to run the waveform computer program. Inputs to the program are described in the text so it is not necessary here to list them. IWVFM=1, NBAR=10, BRECT=0.(window function), TIM=.0993809, SLOBE=-35., BW=40., FO=1227.6, IGP=5 . The term called BW is only used when doing the FFT for the

frequency response and sets the bandwidth over which the FFT is performed. The variable called IGP is the number of wavelenths from one packet to another in one group. TIM is calculated in the following way: There should be an exact number of wavelengths from one end of the group to the other. The center of the first finger should be at 0.0 time and the last finger should be at .0993809 microseconds. If the center frequency is multiplied by the time length of the transducer the number of wavelengths in one group comes out $N\lambda = 122$. This variable should be a whole number of wavelengths and the number of packets should be odd so that the peak of the waveform occurs in a packet. There are 25 packets in this particular design. The number of packets may be calculated by the following equation:

$$N_P = \frac{2\,N\lambda + IGP + 1}{2\,IGP}$$

The FFT of the output of the waveform program is shown in Figure 7. Note that it is purely theoretical and contains no matching or insertion loss effects. The spurious lobes are as predicted by Equation 2 at $.8\ F_0$ and $1.2\ F_0$.

B. RUNNING THE MAIN GROUP TRANSDUCER PROGRAM

The main group-type unidirectional transducer computer program for overlap weighted transducers does nothing more than produce computer output for either an E-beam or Gerber plotting machine. The E-beam machine is used for L-band SAW filter masks and the Gerber plotting machine was used for the 250 MHz group-type unidirectional device.

Inputs to the program are not described in the program itself and so will be listed here. The input data card contains:

IGP=5, The number of acoustic wavelengths from the center of one packet to the next.

VEL=.123561, The acoustic velocity in inches per microsecond

FO=1227.6, The device center frequency, Megahertz

TIM=.0993809, The acoustic time length, Microseconds

BMWID=.00[illegible], The transducer beamwidth at full overlap, inches

FING=.025, Finger width in mils

RED= XXXX, Reduction ratio for Gerber plotter photomasks

The waveform data cards follow the data card described above.

The computer program consists of a main routine and many other subroutines. The DO loop numbered 20 in the main routine is the heart of the program. The transducer is constructed from left to right with the left side being 0. Figure 2 looks much like the final transducer. First are some ground fingers to set the acoustic velocity. The subroutine for calculating the location and size of these fingers is called GRFING. Next are the periodic ground fingers called GRD1. After that, the first packet of PHASE1(group 1) is calculated. Then the second set of ground fingers is called and after that PHASE2 (Group 2) is calculated. The process is repeated until all packets are finished. Some sample E-Beam data output is also shown in Section 4.

C. WAVEFORM COMPUTER PROGRAM

```
      IMPLICIT REAL*8(A-H,O-$)
      DIMENSION A(4000)
      PI = 3.14159265358979300
C*******************************************************************************
C   IWVFM = 1 FOR A DOLPH  OR  0 FOR A GAUSSIAN  WEIGHTING FUNCTION
C
C          (SET SLOBE = 0 AND IWVFM = 0 FOR A TRUNCATED SINX/X WAVFM)
C
C   NBAR = NUMBER OF TERMS IN THE TAYLOR EXPANSION FOR THE DOLPH FUNCTION
C
C   BRECT = FREQUENCY DOMAIN TRUNCATION FUNCTION IN MHZ
C
C   TIM = LENGTH OF THE TRANSDUCER IN MICROSECS (EVEN NUMBER OF WAVELENGTHS)
C
C   SLOBE = SIDELOBE LEVEL IN DB ( USE A MINUS FOR DOLPH AND + FOR GAUSSIAN)
C
C   F0 = CENTER FREQUENCY IN MHZ
C
C   BW = FINAL BANDWIDTH OF THE TRANSDUCER IN MHZ
C
C*******************************************************************************
C
      READ(5,42) IGP
      READ(5,8)IWVFM,LGR,NBAR,BRECT,TIM,SLOBE,F0,BW
      WRITE(6,8)IWVFM,LGR,NBAR,BRECT,TIM,SLOBE,F0,BW
    8 FORMAT(2I5,I4,  2D15.9,D10.4,2D15.9)
   42 FORMAT(I5)
      FPER = 2.*F0
      IF (SLOBE .EQ. 0.D0) GO TO 31
      IF (IWVFM .EQ. 1) GO TO 11
      GO TO 13
   11 WRITE (6,12)
   12 FORMAT(//' THIS IS A DOLPH WEIGHTED TRANSDUCER')
      GO TO 15
   13 WRITE (6,14)
   14 FORMAT(//' THIS IS A GAUSSIAN WEIGHTED TRANSDUCER')
      GO TO 15
   31 WRITE (6,32)
   32 FORMAT (//' THIS IS A TRUNCATED SINX/X WEIGHTED TRANSDUCER')
   15 WRITE (6,30) F0
   30 FORMAT(//' CENTER FREQUENCY = ',F10.3,' MHZ.')
      WRITE (6,40) TIM
   40 FORMAT(/' TRANSDUCER LENGTH = ',F11.8,' MICROSECONDS.')
      WRITE (6,50) SLOBE
   50 FORMAT(/' SIDELOBE LEVEL = ',F5.0,' DB.')
      WRITE (6,60) BRECT
   60 FORMAT(/' BRECT = ',F11.8,' MEGAHERTZ.')
      WRITE (6,70) NBAR
   70 FORMAT(/' NBAR = ',I3,' TERMS IN THE TAYLOR EXPANSION.')
      WRITE (6,80) BW
   80 FORMAT (/' BW    = ',F9.4,'MEGAHERTZ')
C
      TTT=TIM/2.D0
      SIGS = .2302585092994045D0*SLOBE/2.D0/(TTT**2)
      KEYDOL = 1
      IF (IWVFM .EQ. 0) GO TO 7
```

```
      CALL DOLPH(T,TTT,DUM,KEYDOL,PI,NBAR,SLOBE)
    7 KEYDOL = 2
      KK = TIM*FPER + 1.5
      DIST=1.D0/FPER
      BIGST = 0.D0
      II=2*IGP
      DO 2 N=1,KK,II
      DO 41  L=1,II
      I=N+L-1
      T = -TIM/2.D0 + (I-1)/FPER
      A(4*I-1)=T + TIM/2.D0
      IF(T .LT. 0.D0)T=-T
      A(4*I) = 1.D0
      IF(BRECT.EQ.0.D0)GO TO 100
      IF(T .EQ. 0.D0)GO TO 100
      A(4*I)=DSIN(PI*BRECT*T)/(PI*BRECT*T)
  100 CONTINUE
      A(4*I-3) = A(4*I)/DABS(A(4*I))
      IF(L.LE.IGP)A(4*I)=1.D0
      IF(L.GT.IGP)A(4*I)=0.D0
      IF(IWFM .EQ. 1) GO TO 10
      DUM = DEXP(-SIGS*T**2)
      GO TO 20
   10 CALL DOLPH(T,TTT,DUM,KEYDOL,PI,NBAR,SLOBE)
   20 A(4*I)=A(4*I)*DUM*DCOS(2.D0*PI*F0*T)
      A(4*I-2)=I
      IF(DABS(A(4*I)) .GT. BIGST)BIGST=DABS(A(4*I))
   41 CONTINUE
    2 CONTINUE
C
C
      WRITE (6,21)
   21 FORMAT(1H1,25X,' TIME WAVEFORM DATA (LOOK FOR PUNCHED CARDS)')
      WRITE (6,22)
   22 FORMAT(1H0,25X,'*********************************************')
      WRITE (6,4) KK
    4 FORMAT (/' NUMBER OF SAMPLES = ',I5)
      WRITE (6,16) BIGST
   16 FORMAT (/' LARGEST SAMPLE =',D20.14)
      WRITE (6,23)
   23 FORMAT(//,12X,'ENVELOPE',21X,'SAMPLE',19X,'TIME IN',21X,'ELEMENT')
      WRITE(6,24)
   24 FORMAT(14X,'SIGN',23X,'NUMBER',18X,'MICROSECS',19X,'AMPLITUDE')
      WRITE (6,9)
    9 FORMAT (13X,'*******'  [illegible]X,'*******',16X,'*********',19X,'*********')
      DO 6 I=1,KK
      A(4*I) = A(4*I)/BIGST
    6 CONTINUE
      BIGST = 1.D0
      IO=1
      WRITE(7,8)    IO,LOR,NBAR,BRECT,TIM,SLOBE,F0,BW
      WRITE(7,5)KK,BIGST
    5 FORMAT(I5,D20.14)
      WRITE(6,1)(A(4*I-3),A(4*I-2),A(4*I-1),A(4*I),I=1,KK)
    1 FORMAT (13X,F4.0,19X,F10.0,16X,F12.8,14X,D20.14)
      WRITE(7,3)(A(4*I-3),A(4*I-2),A(4*I-1),A(4*I),I=1,KK)
```

```
      WRITE(7,90)(A(4*I-3),A(4*I),I=1,KK)
   90 FORMAT (11X,F4.0,25X,F15.1.)
    3 FORMAT(D20.14)
      END
```

```
      SUBROUTINE DOLPH(T,TTT,DUM,KEYDOL,PI,NBAR,SLOBE)
      IMPLICIT REAL*8(A-H,O-$)
      DIMENSION F(50)
      IF(NBAR .EQ. 0)DUM=1.D0
      IF(NBAR .EQ. 0)RETURN
      BARN = NBAR
      NBAR = NBAR - 1
      IF(KEYDOL .EQ.2)GO TO 10
      ALOB =(DARCOSH(1.D0/DEXP10(SLOBE/20.D0)))/PI
      SIGP = BARN/(DSQRT(ALOB**2 + (BARN-.5D0)**2))
      DO 3 M=1,NBAR
      Y = 1.D0
      X = 1.D0
      AM = M
      DO 1 I=1,NBAR
      AI = I
      IF(I .EQ. M)GO TO 1
      X = X*(1.D0 - (AM**2/AI**2))
    1 CONTINUE
      DO 2 I=1,NBAR
      YI = I
    2 Y = Y*(1.D0-AM**2/((ALOB**2 + (YI-.5D0)**2)*SIGP**2))
      Z = .5D0*((-1)**(M+1))
      F(M) = Z*Y/X
    3 CONTINUE
      GO TO 11
   10 CONTINUE
      DUM = 1.D0
      DO 5 I=1,NBAR
    5 DUM = DUM + 2.D0*F(I)*DCOS(PI*I*T/TTT)
   11 NBAR = BARN
      RETURN
      END
```

```
1  0  100.0            0.9938091000D-01-.35000D+020.1227600000D+040.4000000000D+02

THIS IS A DOLPH WEIGHTED TRANSDUCER

CENTER FREQUENCY =   1227.600 MHZ.

TRANSDUCER LENGTH =  0.09938091 MICROSECONDS.

SIDELOBE LEVEL =  -35. DB.

BRECT =  0.0          MEGAHERTZ.

NBAR =  10 TERMS IN THE TAYLOR EXPANSION.

BW    =    40.0000MEGAHERTZ
```

WAVEFORM DATA (LOOK FOR PUNCHED CARDS)

****

.2D+01

SAMPLE NUMBER ******	TIME IN MICROSECS *********	ELEMENT AMPLITUDE *********
1.	0.0	0.20020905475568D+00
2.	0.00040730	-.20013320456567D+00
3.	0.00081460	0.19991340239330D+00
4.	0.00122190	-.19957170868338D+00
5.	0.00162920	0.19914431494725D+00
6.	0.00203649	0.0
7.	0.00244379	0.0
8.	0.00285109	0.0
9.	0.00325839	0.0
10.	0.00366569	0.0
11.	0.00407299	0.19812131934611D+00
12.	0.00448029	-.19886549970809D+00
13.	0.00488759	0.20011279727539D+00
14.	0.00529488	-.20186561997401D+00
15.	0.00570218	0.20419676577497D+00
16.	0.00610948	0.0
17.	0.00651678	0.0
18.	0.00692408	0.0
19.	0.00733138	0.0
20.	0.00773868	0.0
21.	0.00814598	0.23174372434278D+00
22.	0.00855327	-.23855662180121D+00
23.	0.00896057	0.24592085409320D+00
24.	0.00936787	-.25378366960894D+00
25.	0.00977517	0.26208651730514D+00
26.	0.01018247	0.0
27.	0.01058977	0.0
28.	0.01099707	0.0
29.	0.01140437	0.0
30.	0.01181167	0.0
31.	0.01221896	0.31768542577192D+00
32.	0.01262626	-.32739332407906D+00
33.	0.01303356	0.33741271779616D+00
34.	0.01344086	-.34681811271590D+00
35.	0.01384816	0.35649244829444D+00
36.	0.01425546	0.0
37.	0.01466276	0.0
38.	0.01507006	0.0
39.	0.01547735	0.0
40.	0.01588465	0.0
41.	0.01629195	0.41384515816060D+00
42.	0.01669925	-.42339049080672D+00
43.	0.01710655	0.43297687181112D+00
44.	0.01751385	-.44262107881172D+00
45.	0.01792115	0.45233753718806D+00
46.	0.01832845	0.0
47.	0.01873574	0.0
48.	0.01914304	0.0
49.	0.01955034	0.0
50.	0.01995764	0.0
51.	0.02036494	0.51250351173345D+00

52.	0.02077224	-.52281610612723D+00
53.	0.02117954	0.53318104596073D+00
54.	0.02158684	-.54358182035655D+00
55.	0.02199413	0.55400093932730D+00
56.	0.02240143	0.0
57.	0.02280873	0.0
58.	0.02321603	0.0
59.	0.02362333	0.0
60.	0.02403063	0.0
61.	0.02443793	0.61599099784568D+00
62.	0.02484523	-.62612001719283D+00
63.	0.02525253	0.63617266566713D+00
64.	0.02565982	-.64614764727001D+00
65.	0.02606712	0.65604570757508D+00
66.	0.02647442	0.0
67.	0.02688172	0.0
68.	0.02728902	0.0
69.	0.02769632	0.0
70.	0.02810362	0.0
71.	0.02851092	0.71399257829525D+00
72.	0.02891821	-.72343842673379D+00
73.	0.02932551	0.73282580414926D+00
74.	0.02973281	-.74215171764811D+00
75.	0.03014011	0.75141121582654D+00
76.	0.03054741	0.0
77.	0.03095471	0.0
78.	0.03136201	0.0
79.	0.03176931	0.0
80.	0.03217660	0.0
81.	0.03258390	0.81509174166665D+00
82.	0.03299120	-.82362504361969D+00
83.	0.03339850	0.83201053403732D+00
84.	0.03380580	-.84023660482983D+00
85.	0.03421310	0.83830100264481D+00
86.	0.03462040	0.0
87.	0.03502770	0.0
88.	0.03543500	0.0
89.	0.03584229	0.0
90.	0.03624959	0.0
91.	0.03665689	0.88293455967302D+00
92.	0.03706419	-.88973736652535D+00
93.	0.03747149	0.89630112794677D+00
94.	0.03787879	-.90280780355321D+00
95.	0.03828609	0.90907905870963D+00
96.	0.03869339	0.0
97.	0.03910068	0.0
98.	0.03950798	0.0
99.	0.03991528	0.0
100.	0.04032258	0.0
101.	0.04072988	0.94300879305187D+00
102.	0.04113718	-.94802092440917D+00
103.	0.04154448	0.95283489459047D+00
104.	0.04195178	-.95744332878522D+00
105.	0.04235907	0.96183851688037D+00
106.	0.04276637	0.0
107.	0.04317367	0.0
108.	0.04358097	0.0
109.	0.04398827	0.0
110.	0.04439557	0.0
111.	0.04480287	0.98333925904673D+00
112.	0.04521017	-.98606397526679D+00
113.	0.04561746	0.98853735939639D+00
114.	0.04602476	-.99076020675354D+00
115.	0.04643206	0.99273448653464D+00
116.	0.04683936	0.0
117.	0.04724666	0.0

118.	0.04765396	0.0
119.	0.04806126	0.0
120.	0.04846856	0.0
121.	0.04887586	0.99955537624565D+00
122.	0.04928315	-.99988898136536D+00
123.	0.04969045	0.10000000000000D+01
124.	0.05009775	-.99968698363817D+00
125.	0.05050505	0.99955538080249D+00
126.	0.05091235	0.0
127.	0.05131965	0.0
128.	0.05172695	0.0
129.	0.05213425	0.0
130.	0.05254154	0.0
131.	0.05294884	0.99273450547308D+00
132.	0.05335614	-.99076022822177D+00
133.	0.05376344	0.98853738341988D+00
134.	0.05417074	-.98606400185999D+00
135.	0.05457804	0.98333928821120D+00
136.	0.05498534	0.0
137.	0.05539264	0.0
138.	0.05579993	0.0
139.	0.05620723	0.0
140.	0.05661453	0.0
141.	0.05702183	0.96183856073448D+00
142.	0.05742913	-.95744337466101D+00
143.	0.05783643	0.95283494280845D+00
144.	0.05824373	-.94802097469162D+00
145.	0.05865103	0.94300884532613D+00
146.	0.05905833	0.0
147.	0.05946562	0.0
148.	0.05987292	0.0
149.	0.06028022	0.0
150.	0.06068752	0.0
151.	0.06109482	0.90907912204390D+00
152.	0.06150212	-.90280780861572D+00
153.	0.06190942	0.89630119481191D+00
154.	0.06231672	-.88973743521226D+00
155.	0.06272401	0.88293463020203D+00
156.	0.06313131	0.0
157.	0.06353861	0.0
158.	0.06394591	0.0
159.	0.06435321	0.0
160.	0.06476051	0.0
161.	0.06516781	0.83830108446744D+00
162.	0.06557511	-.83023868818466D+00
163.	0.06598240	0.82201061904760D+00
164.	0.06638970	-.81362513019383D+00
165.	0.06679700	0.80509182971992D+00
166.	0.06720430	0.0
167.	0.06761160	0.0
168.	0.06801890	0.0
169.	0.06842620	0.0
170.	0.06883350	0.0
171.	0.06924080	0.75141131020817D+00
172.	0.06964809	-.74215181274117D+00
173.	0.07005539	0.73282589969323D+00
174.	0.07046269	-.72343852308800D+00
175.	0.07086999	0.71399267523907D+00
176.	0.07127729	0.0
177.	0.07168459	0.0
178.	0.07209189	0.0
179.	0.07249919	0.0
180.	0.07290648	0.0
181.	0.07331378	0.65604580846537D+00
182.	0.07372108	-.64614774893770D+00
183.	0.07412838	0.63617276812881D+00

184.	0.07453568	-.62612012044639D+00
185.	0.07494298	0.61599110186611D+00
186.	0.07535028	0.0
187.	0.07575758	0.0
188.	0.07616487	0.0
189.	0.07657217	0.0
190.	0.07697947	0.0
191.	0.07738677	0.55400104596911D+00
192.	0.07779407	-.54358192690137D+00
193.	0.07820137	0.53318115222740D+00
194.	0.07860867	-.52281621194040D+00
195.	0.07901597	0.51250361693200D+00
196.	0.07942326	0.0
197.	0.07983056	0.0
198.	0.08023786	0.0
199.	0.08064516	0.0
200.	0.08105246	0.0
201.	0.08145976	0.45233763701789D+00
202.	0.08186706	-.44262117783676D+00
203.	0.08227436	0.43297697016768D+00
204.	0.08268166	-.42339058865445D+00
205.	0.08308895	0.41384525567960D+00
206.	0.08349625	0.0
207.	0.08390355	0.0
208.	0.08431085	0.0
209.	0.08471815	0.0
210.	0.08512545	0.0
211.	0.08553275	0.35649254708613D+00
212.	0.08594005	-.34681821188462D+00
213.	0.08634734	0.33711281720961D+00
214.	0.08675464	-.32739342351981D+00
215.	0.08716194	0.31768552493570D+00
216.	0.08756924	0.0
217.	0.08797654	0.0
218.	0.08838384	0.0
219.	0.08879114	0.0
220.	0.08919844	0.0
221.	0.08960573	0.26208660430106D+00
222.	0.09001303	-.25378375241618D+00
223.	0.09042033	0.24592093209044D+00
224.	0.09082763	-.23855669441536D+00
225.	0.09123493	0.23174379107100D+00
226.	0.09164223	0.0
227.	0.09204953	0.0
228.	0.09245683	0.0
229.	0.09286413	0.0
230.	0.09327142	0.0
231.	0.09367872	0.20419679273784D+00
232.	0.09408602	-.20186564078673D+00
233.	0.09449332	0.20011281242283D+00
234.	0.09490062	-.19888550978292D+00
235.	0.09530792	0.19812132502916D+00
236.	0.09571522	0.0
237.	0.09612252	0.0
238.	0.09652981	0.0
239.	0.09693711	0.0
240.	0.09734441	0.0
241.	0.09775171	0.19914431029184D+00
242.	0.09815901	-.19957170487568D+00
243.	0.09856631	0.19991339947022D+00
244.	0.09897361	-.20013326302755D+00
245.	0.09938091	0.20020905475587D+00

D. APODIZED GROUP-TYPE TRANSDUCER PROGRAM

```
      IMPLICIT REAL *4(A-H,O-$)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
C     ************************
C      IO=0 EBEAM PRINTOUT
C      IO=1 EBEAM PUNCH
C      IO=2 GERBER PRINTOUT
C      IO=3 GERBER PUNCH
C     ************************
      READ 10,IO,IGP,VEL,FO,TIM,BMWID,FING,RED
   10 FORMAT(2I10,F10.6,F10.4,4F10.6)
      PRINT 10,IO,IGP,VEL,FO,TIM,BMWID,FING,RED
      READ4,NPEAKS
      READ3,(S(L),A(L),L=1,NPEAKS)
    3 FORMAT(11X,F4.0,25X,F15.12)
    4 FORMAT(I5)
      BMWD=BMWID/2.*1000.
      DLAM=VEL/FO*1000.
      NG=(IGP-1)/2
      NLAM=(TIM*FO) + NG + 1 + .5
      NGG=NLAM/IGP
      NCTR=NGG/2
      JI=1
      IA=1
      CALL WVFRM(NPEAKS,IA)
      JJ=1
      II=1
      I=2
      IA=1
      DO 20 J=1,NGG
      IF(J.EQ.1)CALL GRFING
      CALL GRD1
      CALL PHASE1(IA)
      CALL GRD2
      CALL PHASE2(IA)
      IF(J.EQ.NGG)CALL GRD1
      IF(J.EQ.NGG)CALL GRFING
      IF(J.EQ.NGG)I=I-1
   20 CONTINUE
      IF(IO.GT.1) GO TO 1
      CALL EBFING(IO,FING)
      CALL EBCON(IO)
      CALL EBPAD(IO)
      GO TO 2
    1 CONTINUE
      CALL GBFING(IO,FING,RED)
      CALL GRCON(IO,FING,RED      )
      CALL GRPAD(IO,FING,RED)
    2 CONTINUE
      END
C
C
C
```

```
      SUBROUTINE WVFRM(NPEAKS,IA)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      IGP=2*NG+1
      II=2*IGP
      DO 1 N=1,NPEAKS,II
      DO 2 L=1,NG
      K=L*2+N-1
      S(IA)=A(K)
      S(IA+NG)=A(K)
      IA=IA+1
    2 CONTINUE
      IA=IA+NG
    1 CONTINUE
      IA=IA-1
      IF(S(1).GT.0.) GO TO 5
      DO 4 L=1,IA
      S(L)=-S(L)
    4 CONTINUE
    5 CONTINUE
      PRINT 3,(L,S(L),L=1,IA)
    3 FORMAT (I5,10X,F15.12)
      RETURN
      END
C
C
C
      SUBROUTINE GRD1
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      X(I)=X(I-1)+DLAM/2.0
      YL(I)=-BMWD-3.*DLAM
      YU(I)=BMWD
      YUU=YU(I)
      YLL=YL(I)
      IF(JI.GT.NGG)YU(I)=-YLL
      IF(JI.GT.NGG)YL(I)=-YUU
      WD(I)=DLAM/4.
      CALL GPAD1
      JI=JI+1
      IF(I.LT.10)JI=1
      I=I+1
      X(I)=X(I-1)+DLAM/4.
      YL(I)=-BMWD
      YU(I)=BMWD+3.*DLAM
      YLL=YL(I)
      YUU=YU(I)
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      IF(JI.GT.NGG)YU(I)=-YLL
      IF(JI.GT.NGG)YL(I)=-YUU
      WD(I)=DLAM/4.
      CALL GPAD2
      I=I+1
      RETURN
      END
C
C
C
      SUBROUTINE PHASE1(IA)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      DO 1 K=1,NG
      X(I)=X(I-1)+DLAM/2.0
      YL(I)=-BMWD-1.7*DLAM
      IF(K.EQ.1)YL(I)=-BMWD-.500*DLAM
      YU(I)=BMWD*S(IA)*2.-BMWD
      YLL=YL(I)
      YUU=YU(I)
      IF(JI.GT.NGG)YU(I)=-YLL
      IF(JI.GT.NGG)YL(I)=-YUU
      WD(I)=DLAM/4.
      IF(K.EQ.1)CALLPIBAR
      IA=IA+1
      I=I+1
      YL(I)=YU(I-1)+DLAM
      YU(I)=BMWD+2.*DLAM
      YLL=YL(I)
      YUU=YU(I)
      IF(JI.GT.NGG)YU(I)=YL(I-1)-DLAM
      IF(JI.GT.NGG)YL(I)=-YUU
      X(I)=X(I-1)
      WD(I)=WD(I-1)
      I=I+1
      IF(K.NE.NG)CALL PHIG
    1 CONTINUE
      RETURN
      END
C
C
C
      SUBROUTINE GRD2
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      X(I)=X(I-1)+9.*DLAM/16.
      YL(I)=-BMWD
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      YU(I)=BMWD+3.*DLAM
      YLL=YL(I)
      YUU=YU(I)
      IF(JI.GT.NGG)YU(I)=-YLL
      IF(JI.GT.NGG)YL(I)=-YUU
      WD(I)=5.*DLAM/8.
      I=I+1
      JI=JI+1
      X(I)=X(I-1)+5.*DLAM/8.
      YL(I)=-BMWD-3.*DLAM
      YU(I)=BMWD
      YLL=YL(I)
      YUU=YU(I)
      IF(JI.GT.NGG)YU(I)=-YLL
      IF(JI.GT.NGG)YL(I)=-YUU
      WD(I)=5.*DLAM/8.
      I=I+1
      RETURN
      END
C
C
C
      SUBROUTINE PHASE2(IA)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMON X,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      DO 1 K=1,NG
      X(I)=X(I-1)+DLAM/2.0
      IF (K.EQ.1)X(I)=X(I-1)+9.*DLAM/16.
      YL(I)= BMWD-S(IA)*2.*BMWD
      YU(I)=BMWD+1.7*DLAM
      IF(K.EQ.NG)YU(I)=BMWD+.500*DLAM
      YLL=YL(I)
      YUU=YU(I)
      IF(JI.GT.NGG)YU(I)=-YLL
      IF(JI.GT.NGG)YL(I)=-YUU
      WD(I)=DLAM/4.
      IF(K.EQ.NG) CALL P2BAR
      IA=IA+1
      I=I+1
      YL(I)=-BMWD-2.*DLAM
      YU(I)=YL(I-1)-DLAM
      YLL=YL(I)
      YUU=YU(I)
      IF(JI.GT.NGG)YU(I)=-YLL
      IF(JI.GT.NGG)YL(I)=YU(I-1)+DLAM
      X(I)=X(I-1)
      WD(I)=WD(I-1)
      I=I+1
      IF(K.NE.NG) CALL PH2G
    1 CONTINUE
      RETURN
      END
C
```

```
C
C
      SUBROUTINE PH1G
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      X(I)=X(I-1)+DLAM/2.
      YL(I)=-BMWD
      YU(I)=BMWD+3.*DLAM
      YLL=YL(I)
      YUU=YU(I)
      IF(JI.GT.NGG)YU(I)=-YLL
      IF(JI.GT.NGG)YL(I)=-YUU
      WD(I)=DLAM/4.
      I=I+1
      RETURN
      END
C
C
C
      SUBROUTINE PH2G
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      X(I)=X(I-1)+DLAM/2.
      YU(I)=BMWD
      YL(I)=-BMWD-3.*DLAM
      YUU=YU(I)
      YLL=YL(I)
      IF(JI.GT.NGG)YL(I)=-YUU
      IF(JI.GT.NGG)YU(I)=-YLL
      WD(I)=DLAM/4.
      I=I+1
      RETURN
      END
C
C
C
      SUBROUTINE GPAD1
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      XPR(JJ)=X(I)+WD(I)/2.
      XPL(JJ)=XPR(JJ)-(NG+.375)*DLAM
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```
      IF(JJ.EQ.NGG+1)XPR(JJ)= XPR(JJ)+(NG+.375)*DLAM
      PADU(JJ)=-BMWD-1.95*DLAM
      PADL(JJ)=PADU(JJ)-1.0
      PU=PADU(JJ)
      PL=PADL(JJ)
      IF(JI.GT.NGG)PADL(JJ)=-PU
      IF(JI.GT.NGG)PADU(JJ)=-PL
      VIAU(JJ)=PADU(JJ)-.15
      VIAL(JJ)=PADL(JJ)
      IF(JI.GT.NGG)VIAL(JJ)=PADL(JJ)+.15
      IF(JI.GT.NGG)VIAU(JJ)=PADU(JJ)
      RETURN
      END
C
C
C
      SUBROUTINE GPAD2
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VIL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VIL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      NG1=NGG+1
      XPL(JJ+NG1)=X(I)-WD(I)/2.
      XPR(JJ+NG1)=XPL(JJ+NG1)+(NG+.375)*DLAM
      IF(J.EQ.1)XPL(JJ+NG1)=XPL(JJ+NG1)-(NG+.375)*DLAM
      PADL(JJ+NG1)=BMWD+1.95*DLAM
      PADU(JJ+NG1)=PADL(JJ+NG1)+1.0
      PU=PADU(JJ+NG1)
      PL=PADL(JJ+NG1)
      IF(JI.GT.NGG)PADU(JJ+NG1)=-PL
      IF(JI.GT.NGG)PADL(JJ+NG1)=-PU
      VIAU(JJ+NG1)=PADU(JJ+NG1)
      VIAL(JJ+NG1)=PADL(JJ+NG1)+.15
      IF(JI.GT.NGG)VIAU(JJ+NG1)=PADU(JJ+NG1)-.15
      IF(JI.GT.NGG)VIAL(JJ+NG1)=PADL(JJ+NG1)
      JJ=JJ+1
      RETURN
      END
C
C
C
      SUBROUTINE PIBAR
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VIL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VIL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
       W=DLAM/4+DLAM/4.*.4
      SLTR(II)=X(I)+DLAM/8.+.2*DLAM/4.
      SLTL(II)=X(I)+DLAM/4.-.2*DLAM/4.
      SSLTL(II)=SLTR(II)-W
      SSLTR(II)=SLTL(II)+W
```

```
      SSLLTL(II)=SLTR(II)-W
      SLTLL(II)=SSLTR(II)
      PHL(II)=X(I)+DLAM/4.-.1*DLAM/4.
      PHR(II)=PHL(II)+(NG-1.125)*DLAM
      VTL(II)=(PHL(II)+PHR(II))/2.-DLAM/4.
      VTR(II)=VTL(II)+DLAM/2.
      SLYU(II)=-BMWD-.075*DLAM
      SLYL(II)=-BMWD-2.0*DLAM
      SSLYL(II)=((SLYU(II))+SLYL(II)) /2.+W/2.
      SSLYLL(II)=SSLYL(II)-W
      PHYL(II)=-BMWD-2.05*DLAM
      PHYU(II)=-BMWD-1.4*DLAM
      VTYL(II)=-BMWD-2.75-2.*DLAM
      VTYU(II)=-BMWD-2.*DLAM
      IF(NG.EQ.1)VTYU(II)=-BMWD-1.4*DLAM
      SLR=SLTR(II)
      SLL=SLTL(II)
      IF(JI.GT.NGG)SLTR(II)=SLL+1.4*DLAM/4.0
      IF(JI.GT.NGG)SLTL(II)=SLR-1.4*DLAM/4.0
      IF(JI.GT.NGG)SSLTL(II)=SLTR(II)-W
      IF(JI.GT.NGG)SSLTR(II)=SLTL(II)+W
      IF(JI.GT.NGG)SSLLTL(II)=SLTR(II)
      IF(JI.GT.NGG)SLTLL(II)=SLTL(II)
      SYU=SLYU(II)
      SYL=SLYL(II)
      SSYL=SSLYL(II)
      SSYLL=SSLYLL(II)
      IF(JI.GT.NGG)SLYL(II)=-SYU
      IF(JI.GT.NGG)SLYU(II)=-SYL
      IF(JI.GT.NGG)SSLYL(II)=-SSYLL
      IF(JI.GT.NGG)SSLYLL(II)=-SSYL
      PYL=PHYL(II)
      PYU=PHYU(II)
      IF(JI.GT.NGG)PHYL(II)=-PYU
      IF(JI.GT.NGG)PHYU(II)=-PYL
      VYL=VTYL(II)
      VYU=VTYU(II)
      IF(JI.GT.NGG)VTYL(II)=-VYU
      IF(JI.GT.NGG)VTYU(II)=-VYL
      RETURN
      END
C
C
C
      SUBROUTINE P2BAR
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
       W=DLAM/4+DLAM/4.*.4
      SLTL(II+NGG)=X(I)-DLAM/8.-.2*DLAM/4.
      SLTR(II+NGG)=X(I)-DLAM/4.+.2*DLAM/4.
      SSLTR(II+NGG)=SLTL(II+NGG)+W
      SSLTL(II+NGG)=SLTR(II+NGG)-W
      SSLLTL(II+NGG)=SSLTL(II+NGG)
```

```
      SLTLL(II+NGG)=SLTL(II+NGG)+W
      PHR(II+NGG)=X(I)-DLAM/4.+.1*DLAM/4.
      PHL(II+NGG)=PHR(II+NGG)-(NG-1.125)*DLAM
      VTL(II+NGG)=(PHR(II+NGG)+PHL(II+NGG))/2.-DLAM/4.
      VTR(II+NGG)=VTL(II+NGG)+DLAM/2.
      SLYU(II+NGG)=+BMWD+2.0*DLAM
      SLYL(II+NGG)=BMWD+.075*DLAM
      SSLYL(II+NGG)=(SLYU(II+NGG)+SLYL(II+NGG))/2.+W/2.
      SSLYLL(II+NGG)=SSLYL(II+NGG)-W
      PHYL(II+NGG)=BMWD+1.4*DLAM
      PHYU(II+NGG)=BMWD+2.05*DLAM
      VTYL(II+NGG)=BMWD+2.*DLAM
      IF (NG.EQ.1)VTYL(II+NGG)=BMWD+1.4*DLAM
      VTYU(II+NGG)=BMWD+2.75+2.*DLAM
      SLL=SLTL(II+NGG)
      SLR=SLTR(II+NGG)
      IF(JI.GT.NGG)SLTL(II+NGG)=SLR-1.4*DLAM/4.
      IF(JI.GT.NGG)SLTR(II+NGG)=SLL+1.4*DLAM/4.
      IF(JI.GT.NGG)SSLTL(II+NGG)=SLTR(II+NGG)-W
      IF(JI.GT.NGG)SSLTR(II+NGG)=SLTL(II+NGG)+W
      IF(JI.GT.NGG)SSLLTL(II+NGG)=SLTR(II+NGG)
      IF(JI.GT.NGG)SLTLL(II+NGG)=SLTL(II+NGG)
      SYU=SLYU(II+NGG)
      SYL=SLYL(II+NGG)
      SSYL=SSLYL(II+NGG)
      SSYLL=SSLYLL(II+NGG)
      IF(JI.GT.NGG)SSLYL(II+NGG)=-SSYLL
      IF(JI.GT.NGG)SSLYLL(II+NGG)=-SSYL
      IF(JI.GT.NGG)SLYL(II+NGG)=-SYU
      IF(JI.GT.NGG)SLYU(II+NGG)=-SYL
      PYL=PHYL(II+NGG)
      PYU=PHYU(II+NGG)
      IF(JI.GT.NGG)PHYL(II+NGG)=-PYU
      IF(JI.GT.NGG)PHYU(II+NGG)=-PYL
      VYL=VTYL(II+NGG)
      VYU=VTYU(II+NGG)
      IF(JI.GT.NGG)VTYL(II+NGG)=-VYU
      IF(JI.GT.NGG)VTYU(II+NGG)=-VYL
      II=II+1
      RETURN
      END
C
C
C
      SUBROUTINE GRFING
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      X(1)=0.
      DO 10 M=1,4
      X(I)=X(I-1)+DLAM/2.
      YU(I)=BMWD+2.*DLAM
      YL(I)=-YU(I)
      WD(I)=DLAM/4.
```

```
      I=I+1
   10 CONTINUE
      RETURN
      END
C
C
C
      SUBROUTINE EBFING(IU,FING)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      PRINT5
    5 FORMAT(1H,20X,'E-BEAM DATA FOR TRANSDUCER FINGERS')
      IF(IU.EQ.1)PUNCH5
      M=I+1
      DO 7 L=2,M
      X(L-1)=X(L)
      YU(L-1)=YU(L)
      YL(L-1)=YL(L)
      WD(L-1)=WD(L)
    7 CONTINUE
      K=I/2
      W1=DLAM/4.
      DO6 L=1,I
      IF(WD(L).EQ.W1)WD(L)=FING
    6 CONTINUE
      DO 10 L=1,K
      M=2*L-1
      N=2*L
      X1=X(M)-WD(M)/2.
      X2=X(M)+WD(M)/2.
      X3=X(N)-WD(N)/2.
      X4=X(N)+WD(N)/2.
      PRINT 20 ,M,X1,YL(M),X2,YU(M),X3,YL(N),X4,YU(N)
      IF(IU.EQ.1)PUNCH21,X1,YL(M),X2,YU(M),X3,YL(N),X4,YU(N)
   10 CONTINUE
   20 FORMAT(1H ,I5,'(',F7.3,',',F7.3,')RECT(',F7.3,',',F7.3,');(',
     XF7.3,',',F7.3,')RECT(',F7.3,',',F7.3,')')
   21 FORMAT(         '(',F6.3,',',F6.3,')RECT(',F6.3,',',F6.3,');(',
     XF6.3,',',F6.3,')RECT(',F6.3,',',F6.3,')')
      RETURN
      END
C
C
C
      SUBROUTINE GBFING(IU,FING,RED)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
```

```
      PRINT5
    5 FORMAT(1H,20X,'GERBER DATA FOR TRANSDUCER FINGERS')
      IF(IO.EQ.3)PUNCH5
      GRB=10.*RED
      M=I+1
      DO 7 L=2,M
      X(L-1)=X(L)
      YU(L-1)=YU(L)
      YL(L-1)=YL(L)
      WD(L-1)=WD(L)
    7 CONTINUE
      W1=DLAM/4.
      W3=3.*DLAM/8.
      IW4=W3*RED*1.1
      IW4=IW4*10
      DO6 L=1,I
      IF(WD(L).EQ.W1)WD(L)=FING
      IF(WD(L).EQ.W3) WD(L)=IW4
    6 CONTINUE
      K=I/2
      DO 10 L=1,K
      M=2*L-1
      N=2*L
      IM=X(M)*GRB
      IN=X(N)*GRB
      IL1=YL(M)*GRB
      IU1=YU(M)*GRB
      IL2=YL(N)*GRB
      IU2=YU(N)*GRB
      MW=WD(M)
      NW=WD(N)
      PRINT 30,M,MW,IM,IL1,IM,IU1
      PRINT 30,N,NW,IN,IU2,IN,IL2
      IF(IO.EQ.3) PUNCH 31,MW,IM,IL1,IM,IU1
      IF(IO.EQ.3) PUNCH31,NW,IN,IU2,IN,IL2
   10 CONTINUE
   30 FORMAT(1H ,I5,5X,'LIN ',5X,I6,7X,4I7)
   31 FORMAT(10X,'LIN ',5X,I6,7X,4I7)
      RETURN
      END
C
C
C
      SUBROUTINE EBCON(IO)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      PRINT 1
    1 FORMAT(1H1,20X,'CONNECTING BARS FOR PHASE 2 FINGERS')
      IF(IO.EQ.1)PUNCH1
      L=NGG*2
      DO 2 K=1,L
      IF(NG.EQ.1)GO TO 3
      IF(IO.EQ.1)PUNCH 21,PHL(K),PHYL(K),PHR(K),PHYU(K),VTL(K),VTYL(K),
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     CVTR(K),VTYU(K)
      PRINT20,K,PHL(K),PHYL(K),PHR(K),PHYU(K),VTL(K),VTYL(K),VTR(K),
     CVTYU(K)
    3 CONTINUE
      IF(NG.EQ.1)PRINT10,K,VTL(K),VTYL(K),VTR(K),VTYU(K)
      IF(NG.EQ.1.AND.IO.EQ.1)PUNCH11,VTL(K),VTYL(K),VTR(K),VTYU(K)
      PRINT20,K,SLTL(K),SLYL(K),SSLTR(K),SSLYL(K),SLTLL(K),SSLYLL(K),
     CSSLLTL(K),SSLYL(K)
      PRINT10,K,SLTR(K),SSLYLL(K),SSLTL(K),SLYU(K)
      IF(IO.EQ.1)PUNCH21,SLTL(K),SLYL(K),SSLTR(K),SSLYL(K),
     CSLTLL(K),SSLYLL(K),SSLLTL(K),SSLYL(K)
      IF(IO.EQ.1)PUNCH11,SLTR(K),SSLYLL(K),SSLTL(K),SLYU(K)
    2 CONTINUE
   10 FORMAT(1H ,I5,'(',F7.3,',',F7.3,')RECT(',F7.3,',',F7.3,')')
   11 FORMAT(        '(',F6.3,',',F6.3,')RECT(',F6.3,',',F6.3,')')
   20 FORMAT(1H ,I5,'(',F7.3,',',F7.3,')RECT(',F7.3,',',F7.3,');(',
     XF7.3,',',F7.3,')RECT(',F7.3,',',F7.3,')')
   21 FORMAT(        '(',F6.3,',',F6.3,')RECT(',F6.3,',',F6.3,');(',
     XF6.3,',',F6.3,')RECT(',F6.3,',',F6.3,')')
   22 FORMAT( '(',F6.3,',',F6.3,')HSLANT*',F6.3,'(',F6.3,',',F6.3,')')
   23 FORMAT(1H ,I5, '(',F7.3,',',F7.3,')HSLANT*',F7.3,'(',F7.3,',',F7.3
     X,')')
      RETURN
      END
C
C
C
      SUBROUTINE GRCON(IO,FING,RED)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGC,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      PRINT 1
    1 FORMAT(1H1,20X,'CONNECTING BARS FOR PHASE 2 FINGERS')
      IF(IO.EQ.3)PUNCH1
      GRB=10.*RED
      IFING=FING
      IW=.65*DLAM*RED
      IW=IW*10
      L=NGG*2
      DO 2 K=1,L
      ISU=SLYU(K)*GRB
      ISL=SLYL(K)*GRB
      IYH=((PHYU(K)+PHYL(K))/2.)*GRB
      IVL=VTYL(K)*GRB
      IVU=VTYU(K)*GRB
      IXV=(VTL(K)+VTR(K))/2.*GRB
      ISXL=(SLTL(K)+DLAM*.15)*GRB
      ISXU=(SLTR(K)-DLAM*.15)*GRB
      IHXR=(PHR(K)-.25*DLAM)*GRB
      IHXL=(PHL(K)+.25*DLAM)*GRB
      PRINT 20,K,IW,IXV,IVL,IXV,IVU
      IF(IO.EQ.3)PUNCH 21,IW,IXV,IVL,IXV,IVU
      PRINT 20,K,IW ,IHXR,IYH,IHXL,IYH
      IF(IO.EQ.3)PUNCH 21,IW ,IHXR,IYH,IHXL,IYH
```

```
      PRINT 20,K,IFING,ISXL,ISL,ISXU,ISU
      IF (IO.EQ.3)PUNCH21,IFING,ISXL,ISL,ISXU,ISU
    2 CONTINUE
   20 FORMAT(1H ,I5,5X,'LIN ',5X,I6,7X,4I7)
   21 FORMAT(10X,'LIN ',5X,I6,7X,4I7)
      RETURN
      END
C
C
C
      SUBROUTINE EBPAD(IO)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
     CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLTLL
      PRINT1
    1 FORMAT(1H1,20X,'GROUND PADS')
      IF (IO.EQ.1) PUNCH 1
      JJJ=NGG+1
      DO 10 K=1,JJJ
      J=2*K-1
      L=2*K
      PRINT 20,J,XPL(J),PADL(J),XPR(J),PADU(J),XPL(L),PADL(L),XPR(L),
     CPADU(L)
      IF(IO.EQ.1)PUNCH21,XPL(J),PADL(J),XPR(J),PADU(J),XPL(L),PADL(L),
     CXPR(L),PADU(L)
   10 CONTINUE
   20 FORMAT(1H ,I5,'(',F7.3,',',F7.3,')RECT(',F7.3,',',F7.3,');(',
     XF7.3,',',F7.3,')RECT(',F7.3,',',F7.3,')')
   21 FORMAT(        '(',F6.3,',',F6.3,')RECT(',F6.3,',',F6.3,');(',
     XF6.3,',',F6.3,')RECT(',F6.3,',',F6.3,')')
      PRINT2
    2 FORMAT(1H0,20X,'VIAHOLES FOR TRANSDUCER')
      IF(IO.EQ.1)PUNCH2
      DO15 K=1,JJJ
      J=2*K-1
      L=2*K
      PRINT 20,J,XPL(J),VIAL(J),XPR(J),VIAU(J),XPL(L),VIAL(L),XPR(L),
     CVIAU(L)
      IF(IO.EQ.1)PUNCH21,XPL(J),VIAL(J),XPR(J), VIAU(J),XPL(L),VIAL(L),
     CXPR(L),VIAU(L)
   15 CONTINUE
      RETURN
      END
C
C
C
      SUBROUTINE GRPAD(IO,FING,RED)
      DIMENSION X(700),YL(700),YU(700),WD(700),XPR(100),XPL(100),
     CSLTR(100),SLTL(100),PHL(100),PHR(100),VTL(100),VTR(100),A(700),
     CS(700),PADU(100),PADL(100),VIAU(100),VIAL(100),SLYU(100),SLYL(100)
     C,PHYL(100),PHYU(100),VTYL(100),VTYU(100),SSLYL(100),SSLYLL(100)
     C,SSLTR(100),SSLTL(100),SSLLTL(100),SLTLL(100)
      COMMONX,BMWD,DLAM,YL,YU,WD,I,J,NG,NGG,XPR,XPL,JJ,II,SLTR,SLTL,
     CPHL,PHR,VTL,VTR,A,S,NCTR,PADU,PADL,VIAU,VIAL,SLYU,SLYL,PHYL,PHYU,
```

```
 CVTYL,VTYU,JI,SSLYL,SSLYLL,SSLTR,SSLTL,SSLLTL,SLILL
      PRINT1
    1 FORMAT(1H1,20X,'PADS FOR PHASE1 FINGERS')
      IF (IO.EQ.3) PUNCH 1
      GRB=10.*RED
      IDY=GRB
      IVY=IDY*.85
      IFIN=FING
      JJJ=(NGG+1)*2
      DO 10 K=1,JJJ
      IYPL=PADL(K)*GRB
      IDX=(XPR(K)-XPL(K))*GRB
      IXP=XPL(K)*GRB
      PRINT 20,K,IFIN,IDX,IDY,IXP,IYPL
      IF(IO.EQ.3)PUNCH 21,IFIN,IDX,IDY,IXP,IYPL
   10 CONTINUE
   20 FORMAT(1H ,I5,5X,'REC',6X,I6,4I7)
   21 FORMAT(10X,'REC',6X,I6,4I7)
      PRINT 2
    2 FORMAT(1H0,20X,'VIAHOLES FOR TRANSDUCER')
      IF(IO.EQ.3)PUNCH 2
      DO 15 K=1,JJJ
      IYPL=VIAL(K)*GRB
      IDX=(XPR(K)-XPL(K))*GRB
      IXP=XPL(K)*GRB
      PRINT 20,K,IFIN,IDX,IVY,IXP,IYPL
      IF(IO.EQ.3)PUNCH21,IFIN,IDX,IVY,IXP,IYPL
   15 CONTINUE
      RETURN
      END
```

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